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Natural Replacement of Weed Hosts of the Beet Leafhopper as Affected by Rodents[1]

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WEEDY VEGETATION on cleared and abandoned lands or on unplowed range lands constitutes a large expanse of host plants of the beet leafhopper (*Eutettix tenellus* (Bak.)), vector of the virus that causes curly top of sugar beets, beans, tomatoes, and other economic plants. As a means of beet leafhopper and curly top control, the natural replacement of the weeds on which this leafhopper breeds and feeds by grasses and other plants that are not suitable as hosts of the insect has been an important subject of ecological investigation. The three major causes of the destruction of vegetation on these areas—burning, plowing, and

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excessive grazing by livestock—were studied from 1928 to 1935 and were shown to be chiefly responsible for initiation and perpetuation of the weedy condition of range lands. In the absence of these retrograde factors, weeds very commonly were replaced by annual grasses and permanent range improvement commenced.

Some apparently erratic changes, however, in the successions of vegetation that took place on areas where burning, plowing, and overgrazing were prevented were not explained. The ecological studies as made from 1930 to 1944 on three 40-acre fenced plots and on unfenced tracts in southern Idaho now indicate that such variable behavior was due to destruction of vegetation by native animals, chiefly jack rabbits. These observations, reported and interpreted in this circular, demonstrate that in addition to burning, plowing, and excessive grazing, the feeding by rodents is a factor that in some instances disrupts plant successions and thereby retards the natural replacement of weed hosts of the insect vector of the curly top virus.

The studies of plant successions have thus produced results that are useful as a part of the basic information needed in promoting production of sugar beets and other crops affected by curly top. They also contribute toward a better understanding of range management problems in an area subject to intermittent farming. They should aid in the development of wise land use practices—a consideration of long-time significance and increasing importance.

The studies deal specifically with communities of annual plants found on the desert-dry outlying lands bordering cultivated districts and on range lands that were formerly covered by the northern desert-shrub type of vegetation—sagebrush, with its associated perennial grasses, and herbaceous perennials. Although the communities of annual plants may be different on the nearby foothills and on higher plains and valleys of southern Idaho where the plant cover formerly consisted of other types of native perennial vegetation, some of the essential results of these studies will apply to these areas also, as they have already been found applicable in somewhat similar investigations in the San Joaquin Valley, Calif.

This circular deals with the data obtained and the conclusions derived from their interpretation.

SUMMARY

The vegetation of annuals on three 40-acre plots became more and more unlike during the 6 years that the plots were free from fire, plowing, and from all grazing by livestock but were accessible to jack rabbits. Insofar as uniformity in the changes and replacement of weed hosts by downy chess was expected there was failure. During the same period, in small exclosures within each of these plots where feeding by jack rabbits was prevented, the destruction of vegetation from all causes was so slight that the vegetation of annuals became more and more alike and finally ended with a downy chess cover. Here the results in general

were uniform. They demonstrated the replacement of weed hosts by downy chess and supported previous findings.

Plant Successions

Repeated records for different periods of years, for different places, and for both fenced and unfenced areas show that if the destruction of vegetation is slight or negligible there is a series of changes in the vegetation of annuals: First stage, Russian-thistle (*Salsola pestifer* A. Nels.) ; second stage, mustards, including flixweed tansymustard (*Descurainia sophia* (L.) Webb) and tumblemustard (*Sisymbrium altissimum* L.) ; third stage, downy chess (*Bromus tectorum* L.). They also show that if the destruction of vegetation is marked or excessive the series is either interrupted or, if the downy chess cover has developed, that it is destroyed and communities of Russian-thistle or mustards again appear. In extreme cases the final result is bare soil and erosion. Severe erosion covered about 71 acres partly within one of the fenced plots and about 92 acres on a remote unfenced tract.

The period for development from the two weed-host stages (first, Russian-thistle, then mustards) to the third or annual grass (downy chess) stage was repeatedly shown to be 5 years under conditions of a minimum of destruction of vegetation by any cause. If these conditions are fulfilled, the results can be predicted and an optimum (or near optimum) rate of change established. Similarly, an optimum rate may also be determined for the stages leading to a reestablishment of native perennials, although present concepts of the time required may need to be revised. The method of investigation, namely, establishment of protection areas and appraisal of degrees of destruction of vegetation, suggests an experimental approach to plant successions and an application of some of the essentials of the results to other types of vegetation.

Year-after-year reappearance of Russian-thistle or mustards indicates excessive destruction of vegetation, whereas reappearance of a good cover of downy chess indicates much less destruction, though this may still be too great to permit revegetation by native perennials.

For a particular area and in a given year it may be said that a good downy chess cover affords desirable early-spring feed, that it protects the soil against erosion, and that it is not suitable as a breeding area for beet leafhoppers. Nevertheless, over a long time such cover fails in all these respects. Its forage value may become next to nothing in drought years; it may deteriorate in one season to a leafhopper-breeding area; or in any year or in a few years it may become wind-eroded. Because of its instability, a downy chess cover does not afford economical forage as compared with a cover of perennial grasses.

Effects of Feeding by Rodents

Within the plots fenced against all grazing by livestock, the destruction of vegetation was caused chiefly by the feeding of jack rabbits. Where a dense growth of downy chess had developed and it was not disturbed either by jack rabbits or by livestock there was marked damage by meadow mice.

A destruction of vegetation that causes such a deterioration of the vegetation of annuals as to result in a sparse stand may be primarily the effect of grazing by livestock or of such grazing coupled with burning and with whatever feeding of native animals there may be. Once a sparse stand has been initiated, it may, under some conditions, be continued and accentuated by jack rabbits. Although this effect may be localized, the total effect at times may be considerable, and this possibility has special significance on grazing lands that border cultivated tracts where there is a curly top problem.

Assuming conservative grazing by livestock, failure to obtain development of the desired plant cover in a given time and over a given area suggests the need for determining the extent of harmful destruction of vegetation by rodents or other animals before attributing the failure to some other cause, such as drought or competition. Also, if large-scale reestablishment of the vegetative cover within a short time is planned, it is especially important to realize that destruction of vegetation by rodents may be serious and may necessitate a reduction of their population. After that, the desired cover or a more complete cover over a given area may be developed by reseeding or by natural recovery. On the lands here discussed, rodent control would insure reestablishment of native perennials in a much shorter time, make for more uniform replacement of the weed hosts of the beet leafhopper, and thus contribute to control of the curly top disease.

PLANT-SUCCESSION STUDIES IN CURLY TOP CONTROL

Entomologists have shown the relation of the weed-host areas on the Snake River plains of southern Idaho to beet leafhopper populations and to the annual infestations of crops by this pest (*1, 2, 6*).[3] The extent of weed-host areas, their origin, and the possibilities of control have been discussed elsewhere (*8, 11*). The study of such areas is essentially one of secondary successions on the lower lying lands that are near agricultural tracts and were formerly covered by the northern desert-shrub type of vegetation—sagebrush, its associated perennial grasses, and herbaceous perennials.

Early in these ecological investigations the communities of annuals were distinguished and the stages of succession leading to a reestablishment of the sagebrush and grass cover recognized (*8*). In a recent publication (*9*) an account was given of the course of the changes on a number of former fields (aban-

[3] Italic numbers in parentheses refer to Literature Cited, p. 48.

doned farm land) near Hollister, Idaho, for the period 1928-36, and the causes underlying the changes were indicated. The first and second stages in the successions afforded breeding areas for the beet leafhopper, but the third, or annual-grass stage, did not. Whether such changes took place or whether they were disrupted was dependent generally on the presence or absence of three cover-destructive agencies—plowing, burning, and excessive grazing. The apparently erratic changes on occasional abandoned fields that were free from these agencies, however, were not fully understood until destruction of vegetation by rodents, chiefly jack rabbits, also was prevented.

The three 40-acre fenced plots set up to supplement the studies that had been made on the abandoned lands near Hollister, Idaho, afforded an opportunity to record the changes in a weedy plant cover and the rate of change on larger tracts protected from the three factors, plowing, burning, and excessive grazing. These plots included areas where the vegetation was protected not only from livestock but also from jack rabbits and some of the smaller rodents. Observations on these plots have thus made it possible to demonstrate a fourth factor and also to contrast the processes that constitute development of vegetation ("progressive changes") with those in an area where deterioration ("retrogressive changes") takes place and ends in erosion. The latter processes are significant for curly top control, since retrogressive changes create an environment that is favorable for the beet leafhopper and thus endanger sugar beets and other crops susceptible to curly top.

PROCESSES OF DEVELOPMENT AND OF DETERIORATION CONTRASTED

The processes that take place during development and also deterioration, as recorded in table 1, are generalizations based on conditions found in the present studies and also in those previously published (*9*). The length of time for downy chess to establish a cover—beginning with Russian-thistle and then mustards—has now been shown for various areas and for different periods of years. Likewise, the reasons Russian-thistle does not continue to occupy the ground but gives way to mustards and these in turn to downy chess have been discussed in some detail (*9*). Here the purpose is to give a chronological account not only of the stages of succession but also of the processes during each of successive growing seasons and particularly to contrast these with the processes involved in the retrogressive changes for an equal period. A single picture, no matter how accurate, fails to give a full understanding of the vegetation of an area, particularly where deterioration is taking place, because of excessive destruction of vegetation. In spring there may be a sparse cover; in fall, in the same area, the soil may be drifting.

The picture presented by table 1 begins with the first season's weedy growth on a soil area that is uninhabited—abandoned stubblefield or bare soil if it is not actively eroding. Commonly

TABLE 1.—*Processes that take place in development and in deterioration of areas*

Year and season	Development or progressive changes (Damage by feeding of either livestock or rodents is negligible)	Deterioration or retrogressive changes (Damage by feeding of livestock or rodents, or both, is excessive)
First year:	Initial total number of plants low, but equal to those on unprotected area and not subsequently reduced by feeding of animals.	Initial total number of plants low, equal to those on protected area but gradually reduced by feeding of animals.
	Proportion of species remains approximately as at the beginning.	Proportion of species changes gradually.
Spring.....	Downy chess not abundant, but plants are tall, well-stooled, and mature by end of spring.	Downy chess plants begin well, but are clipped to the ground.
	Mustards, second in abundance, are large and flower at end of spring.	Mustards also are large, and many are clipped.
	Russian-thistle still in the seedling stage, but by far the most abundant.	Russian-thistle in the seedling stage, and a larger proportion of seedlings survive.
Summer	Stand not dense, but plants are well developed and form a cover for most of the soil.	Stand poor and sparse compared with that on protected area; bare soil spaces conspicuous.
	Mustards and downy chess mature and dry; seeds of both are in proportion to initial plant population and remain approximately where they fall.	Downy chess rare or lacking.
		Dry mustards eaten or broken off and blown away, so that seed supply is low.
	Russian-thistle plants large, well-formed.	Russian-thistle plants clipped in increasing numbers.
Fall.....	Mustard and downy chess seeds germinate with the first rain.	The comparatively few mustard and downy chess seeds germinate.
	Russian-thistle dries, and the abundant seeds fall but lie dormant until spring.	Russian-thistle seeds fall, but remain dormant until spring. Wind blows seed off bare soil spaces and piles them around groups of standing plants.
Second year:	Total number of plants of all species greatly increased over previous year and not being decreased.	Total number of plants of all species not increased over previous year and being reduced.
	Downy chess and mustards have increased, each according to its respective capacities. The plants are good-sized and are drawing on the soil moisture supply early.	Downy chess few and soon clipped to the ground.
Spring.....		Mustards not increased, many being deformed or killed by clipping.
	Russian-thistle seeds germinate in large numbers over entire area. At the end of spring the plants are still seedlings, whereas downy chess is mature and mustards are flowering.	Russian-thistle has not increased. Seedlings grouped in patches around old plants. Soil spaces between are bare and larger than in preceding year.
Summer	Downy chess and mustards mature and dry; plants large and well-formed; seeds abundant, and for the mustards the total production is large.	Downy chess almost lacking.
		Mustards few and seeds correspondingly few.
	Russian-thistle plants densely cover the ground. Each plant has only a small soil space from which to draw its soil moisture. In the hot weather when the plants should grow large they show signs of suffering and discoloring.	Russian-thistle plants widely spaced and the few survivors not clipped grow to large plants. Greatly increased spaces between plants wind-swept and topsoil blown away.
Fall.....	Russian-thistle plants have dried prematurely or survivors are dwarfed and produce very little seed.	Russian-thistle survivors remain green long after those in protected area are dry. On these plants a large quantity of seed is produced, but the total for the area is small.
	Downy chess and mustard seeds abundant, particularly the mustards, and germinate with the first rains.	The rare downy chess seeds and the comparatively few mustard seeds germinate with the first rains.

TABLE 1.—*Processes that take place in development and in deterioration of areas*—Continued

Year and season	Development or progressive changes (Damage by feeding of either livestock or rodents is negligible)	Deterioration or retrogressive changes (Damage by feeding of livestock or rodents, or both, is excessive)
Third year:		
Spring.....	Total number of all species high, but composition changed. Mustards now most abundant; downy chess next; Russian-thistle seedlings few or none.	Total number of all species not high. Russian-thistle still the most numerous; mustards few; and the rare downy chess plants have been clipped.
	Mustards and downy chess grow well.	The mustards that escape clipping grow to be large plants.
	The few Russian-thistle seedlings dwarfed.	The Russian-thistle seedlings grow well, with plenty of soil space from which to draw moisture.
Summer	The large, well-formed mustards and downy chess have matured and dried with an abundance of seed. The seeds remain approximately where they fall.	The comparatively few mustards are dry; they are broken off by animals or by the wind and blown away.
	In the dense cover Russian-thistle seedlings have died prematurely or have grown poorly and are inconspicuous.	Russian-thistle plants that survive are green and growing well. There are large open wind-swept spaces; the soil crust is broken, churned to dust, and then blown away.
Fall.....	Mustard seeds particularly abundant and germinate with the first rains.	On the large open soil spaces the wind has blown away seeds as well as topsoil. No seeds germinate here or, if so, the seedlings are cut off by the drifting soil.
	Downy chess also germinates.	
	Russian-thistle dwarfed, with few if any seeds.	Russian-thistle survivors are green late in the season. Soil has piled around them and formed hummocks.
Fourth year:		
Spring.....	Total numbers of all species again increased.	Total numbers of all species again decreased.
	Now there are two species, mustards and downy chess.	There are two species, Russian-thistle and mustards.
	The mustards are dense and as they grow the crowding is accentuated. At the first warm weather the plants suffer from lack of water because of the small soil space each individual plant has to draw on.	Mustards are few and near the hummocks of soil around old Russian-thistle.
		Russian-thistle seedlings abundant on these hummocks.
	Downy chess plants have drawn on the soil moisture before the mustards have grown well and mature before the mustards flower.	In the open soil spaces the surface crust in dry weather is broken, churned to dust, and swept away by the wind.
Summer	The mustards have dried; they are dwarfed, the seeds are few, or they have died prematurely with no seed formed.	
	Downy chess plants are dry, large, and have an abundance of seed.	
	Russian-thistle plants grow poorly if present and produce few or no seeds.	Clipping and the cutting action of drifting soil have greatly reduced the Russian-thistle on the hummocks. Each windy day more soil is swept off the bare places and piled up around the scattered Russian-thistles.
Fall.....	Downy chess seeds abundant and germinate with the first rains.	The few remaining Russian-thistles are green until late in the season, but deformed by clipping; some are nearly buried by soil drifting from open spaces.
	Mustard seedlings much less abundant.	

TABLE 1.—*Processes that take place in development and in deterioration* —Continued

Year and season	Development or progressive changes (Damage by feeding of either livestock or rodents is negligible)	Deterioration or retrogressive changes (Damage by feeding of livestock or rodents, or both, is excessive)
Fifth year:	Total numbers of all species again increased.	Total numbers of all species again decreased.
Spring.....	Downy chess now dominant. Sites of older colonies now covered with a dense, short stand that matures early. Other areas have a sparse stand of larger plants and some mustards.	
	Mustards few and scattered.	Mustards few.
	Russian-thistle rare or lacking.	Russian-thistle practically the only species; seedlings clustered around the hummocks near old plants; open spaces wind-swept and bare of all plants.
Summer	All the plant cover is dry. The mustards are poor, spindly, or prematurely dry except in small areas where downy chess is sparse.	Clouds of dust are swept up each windy day. The Russian-thistle that has escaped clipping has been cut off by the drifting soil.
Fall.....	The abundant seeds of downy chess germinate with the first rains, and the stand of seedlings is dense.	The hummocks have been leveled, and the entire soil surface is bare of all plants. Erosion cuts deeper into the lower layers (6 inches), and blowing extends into the winter, when snow and soil blow away in a mixture of the two.
	Mustard seedlings are few or lacking.	

Russian-thistle is the most abundant, mustards next, and downy chess least, though either of the last two may be the most numerous the first year if there is a heavy influx of seed from a contiguous area. That any one of these plants does not need to precede the other and to prepare the soil for it is known from trial plantings. All are prolific in seed production, but Russian-thistle is considered to be the most efficient, and to this is attributed its greater abundance on newly exposed and unoccupied soil.

The obvious difference between development and deterioration is that in the former the trend was toward a great increase in the total number of plants during the 5 years, whereas in the deterioration there was a general decrease for the same period. Although the immediate cause for this difference is death of the plants from the feeding of animals during the retrogressive changes, it is not in itself a sufficient explanation, because large numbers also died during the progressive changes (Russian-thistle second year and mustards fourth year, table 1).

Role of Plant Characteristics in Development

The difference is that, though Russian-thistle died in large numbers during the progressive changes, in the same year mustards and downy chess grew well and increased according to their capacity for the production and distribution of seed instead of being killed out, as happened in deterioration. These two escape the severe competition of the large numbers of Russian-thistle by

maturing at a time when Russian-thistle is still in the seedling stage. This timing of growth, as determined by two plant characteristics—prior germination and prior maturity—enables the mustards and downy chess to draw on the soil moisture according to their requirements and to deplete it before the Russian-thistle plants are large enough to afford severe competition. In the uncrowded conditions of the first year, when the plants were well spaced, all the species, including Russian-thistle, grew well, and in the following season they increased in numbers according to their respective capacities for seed production and distribution.

Thus the processes that determine the initial abundance of each of the species, the subsequent increase in their numbers, and the survival of a particular one under severe competition are all dependent on plant characteristics—the first two on seed production and distribution and the third on the time of growth, i.e., prior germination and prior maturity.

These characteristics are fixed, in the sense that while each varies somewhat for a particular species, all retain a proportionate relation with respect to the same characteristic in the competitive species. Thus, though the actual date either of germination or of maturity varies considerably with the season, downy chess retains priority with respect to the other species, so that it is the first to draw on the soil moisture. Again, the proportion of the number of individuals of the species in the first year varies, and yet, because of the high total numbers of all species in the following season, Russian-thistle is eliminated as a dominant in the subsequent plant cover, though not necessarily as a possible admixture.

Drought, together with crowding, may completely eliminate a species from the field in the subsequent plant cover, as flixweed in field No. 4 at Hollister (*9*); nevertheless without the drought flixweed would be eliminated as a dominant because of the crowding, although it might enter as an admixture in the plant cover of the following season. Thus, drought can be said to accentuate the changes and to set them off more sharply, but not to determine them (*9*); and the development proceeds from one stage to the next despite the differences in weather for the series of years.

Whether the stages are sharply marked and represent nearly pure stands or whether they are somewhat obscured by admixtures, the development to a downy chess cover in protected areas takes place in 5 years. It is a fixed period, allowing for the minor variations noted, since it is dependent on fixed characteristics of the species involved. Thus, if destruction of vegetation is slight or negligible, the prediction can be made that a downy chess cover will develop in 5 years.

Role of Excessive Destruction of Vegetation in Retrogressive Changes

During the retrogressive changes the great increase in numbers of plants is interfered with because the parent plants (the potential seed supply) are constantly being killed off. The high crowd-

ing numbers that tend to eliminate Russian-thistle are lacking, and its continuation as a dominant is favored. Moreover, individuals of downy chess and, to a less extent, mustards are few in number; and when a species is low in numbers the feeding of animals affects it drastically. Here there is a definite tendency to eliminate downy chess and, to a less extent, mustards. This actually happens where feeding is excessive, and it may also happen to Russian-thistle later, once its numbers become low.

These processes in deterioration then are not dependent on the characteristics of the plants but chiefly on the rate of destruction by the feeding of animals, which is, in turn, greatly accentuated by drought and by a resultant shortage of forage. It seems plain that the effect of these processes cannot be predicted without first knowing the rates of destruction and then knowing from trials how to interpret these rates.

Controlled Succession Possible

The data accumulated in the last few years show more and more that the development through the stages of succession to downy chess will proceed despite fluctuations of weather (wet and dry years) if destruction of vegetation is slight or negligible. In other words, the successions can be induced to go through the stages or they can be halted or reversed by manipulating damage to vegetation, by preventing an excess, or by causing an excess. Within the specified limitations the communities of annuals can be molded as desired.

HOST PLANTS OF THE BEET LEAFHOPPER

The species of plants that most commonly play a part in the early stages of secondary successions on abandoned lands in southern Idaho are Russian-thistle, mustards, including flixweed and tumblemustard, and the annual grass, downy chess. These are all introduced species. With the exception of downy chess, all are favorable for the production of high leafhopper populations (*2, 6*).[4]

Less frequently the following native species also are present and locally may sometimes be prominent: Green tansymustard (*Descurainia longipedicellata* (Fourn.) O. E. Schulz); an annual grass, sixweeks fescue (*Festuca octoflora* Walt.); borages, stickseed (*Lappula redowskii* (Hornem.) Greene and *L. texana* (Scheele) Britton); nievetas (*Cryptantha ambigua* (A. Gray) Greene); and also two small borages (*Pectocarya penicillata* (Hook. and Arn.) A. DC. and *Cryptantha circumscissa* (Hook. and Arn.) Johnst.). Though not generally prominent on abandoned lands, they are widespread on uncleared sagebrush land (*8*) and, together with other native annuals, grow wherever the perennial grasses and other native perennials have been killed out in the interspaces between the shrubs. Such weedy stands, if green

[4] Where citations to literature are not given with regard to the relations of host plants to the beet leafhopper, the statements are based on information obtained from the Bureau of Entomology and Plant Quarantine, Twin Falls, Idaho.

tansymustard is abundant, are very favorable for the production of high leafhopper populations in spring (*2, 6*).

Within restricted areas there are found tumbleweed (*Amaranthus graecizans* L.), redscale (*Atriplex rosea* L.), prickly lettuce (*Lactuca serriola* f. *integrifolia* Bogenh.), cutleaf nightshade (*Solanum triflorum* Nutt.), and narrowleaf goosefoot (*Chenopodium leptophyllum* Moq.). Of these, the first three are introduced plants. All five vary in their suitability as hosts of the beet leafhopper and, though some may be favorable for the production of high numbers of this insect, all are of restricted abundance in semidesert land. Redscale was more abundant in southern Idaho prior to 1930. It is less adapted to withstand crowded conditions and the very dry summers than is Russian-thistle, to which it is similar in growth period and in the role it plays in the successions; it is now limited to old corrals and newly disturbed soil, where it grows well only if widely spaced.

Other weed-host plants found on abandoned or denuded land, but not on the three fenced plots, are blistercress (*Cheirinia* spp.) and peppergrass (*Lepidium perfoliatum* L., and *L. densiflorum* Schrad.). Smotherweed (*Bassia hyssopifolia* (Pall.) Kuntze) is abundant along ditchbanks and on cleared greasewood (*Sarcobatus vermiculatus* (Hook.) Torr.) lands, but not on desert-dry, cleared sagebrush lands.

In one of the plots at least, native perennials that are not hosts are rapidly replacing the weed hosts. Aside from sagebrush (*Artemisia tridentata* Nutt.), the perennials are chiefly grasses—squirreltail (*Sitanion hystrix* (Nutt.) J. G. Smith), streambank wheatgrass (*Agropyron riparium* Scribn. and Smith), Thurber needlegrass (*Stipa thurberiana* Piper), and Sandberg bluegrass (*Poa secunda* Presl). Indian ricegrass (*Oryzopsis hymenoides* (Roem. and Schult.) Ricker), once common in the sagebrush and grass vegetation, has largely disappeared and is rare in the plots.

Less abundant but widespread perennials are rattleweed (*Astragalus salinus* Howell), globemallow (*Sphaeralcea grossulariaefolia* (Hook. and Arn.) Rydb.), and fleabane (*Erigeron concinnus* (Hook. and Arn.) Torr. and Gray).

TERMS USED

The term "weeds" includes not only Russian-thistle, mustards, and other dicotyledonous annuals but also the annual grasses, as downy chess and sixweeks fescue. The weedy plant cover then refers to a vegetation of annuals, including grasses. It is not confined to lands that have been plowed and then abandoned, but occurs also on unplowed grazing lands wherever denudation is complete. Weed-host areas include some of the communities of the weedy plant cover, as Russian-thistle and mustards, but not the annual grasses. Sometimes a partial denudation occurs within the stable native sagebrush and grass type, so that the grasses between the shrubs are killed out and the spaces occupied by weeds. This "sagebrush with weeds" and the weed-host areas previously mentioned are referred to only occasionally, whereas

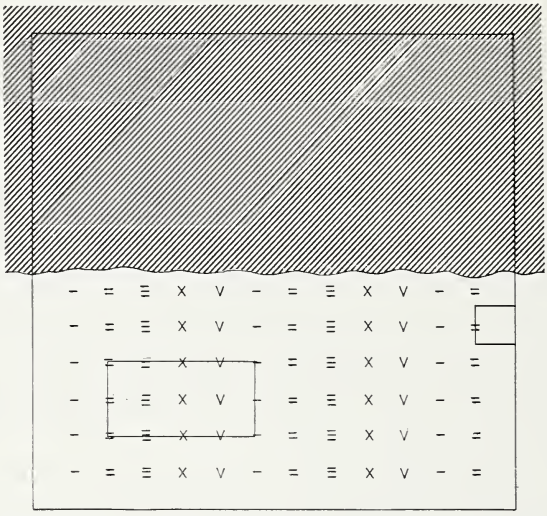

FIGURE 1.—General plan of the 40-acre fenced plots. Within the outer lines of the large square, which represent a livestock fence, are two areas closed to jack rabbits as well as livestock, one a 100-foot square (right) and the other a 200- by 400-foot rectangle. The shaded part represents sagebrush, the unshaded part cleared land covered with a growth of annuals. The cleared part is subdivided into 100-foot squares permanently marked by 5-foot corner stakes with distinctive top crosspieces to represent numbers 1 to 5. The numbering begins at the left, proceeds to 5, and begins over again.

FIGURE 2.—General view of the Castleford plot, showing the steel tower at the border between sagebrush and weedy cover and the 5-foot stakes (right) used to subdivide the plot, as described in figure 1. The stakes served to locate the observer on a particular 100-foot square anywhere in the weedy part and aided in mapping or photographing the plant cover from the tower. (Sept. 26, 1932.)

the major part of this circular is concerned with the weedy plant cover.

The vegetation of annuals is composed of distinct communities that do not appear simultaneously on the abandoned lands (i.e., on the same area in the same growing season), but if there is not too much destruction of vegetation by the feeding of animals or by some other agency they follow one another in a series of stages, beginning with Russian-thistle as the dominant species in the first years, then mustards, and end about the fifth year with a cover of downy chess. The observations made in working with these simple communities indicate (1) that the stages, or plant successions, are dependent on characteristics of the communities, i.e., of the constituent species, and (2) that deterioration—the shift from a downy chess cover of one season to one of mustards or Russian-thistle the following season—is due to destruction of vegetation. The terms "development" and "plant successions" are limited in Clements' (*3*) sense to the changes under (1), the series of stages or progressive changes; and the changes under (2) are referred to as deterioration or retrogressive changes. The term "changes" is a general one that includes both the orderly development, or plant successions, and the irregular shifts in vegetation due to destruction. The term "processes," as used in table 1, is all-inclusive as to details, either of seasonal development and of variations in density within a community or of shifts in the dominant annual species.

DESCRIPTION OF THE THREE PLOTS

The three 40-acre fenced plots are situated on the semidesert Snake River plains of southern Idaho, the general area of which has been described elsewhere (*8, 9*). Specific locations of the three plots (Burley, Castleford, and Wendell) and other pertinent data are given in table 2. Approximately half of each plot consisted of a weed cover and the other half of sagebrush with weeds (fig. 1). Parts of the plots were later protected against jack rabbits, p. 17. Each plot was equipped with a 50-foot tower (fig. 2) used for photographing and for sketching on a base map the boundaries of the various weed areas.

DETERMINING CHANGES IN VEGETATION

The changes in vegetation were determined by the visual-estimate and by sampling methods. To denote gross changes the visual estimate sufficed, and the area covered by the principal weeds was determined in this way.

Because of differences in the time of maturing of downy chess, mustards, and Russian-thistle, the areas were for the most part readily separated, but slight differences, as in mixtures, were much more readily distinguished from the 50-foot tower than from the ground. Accordingly, the boundaries of the various weed areas were first roughly sketched from the tower on a base map with the guidance of the 5-foot stakes shown in figures 1 and 2. The boundary lines were then located more accurately on the ground by walking along the row of stakes and noting the points of transition within each 100-foot square.

In the sampling method, composition and density were recorded on small unit areas (1/16-square-meter quadrats) each permanently marked by pegs,

TABLE 2.—*Descriptions of the three 40-acre fenced plots in southern Idaho*

Name of plot	Distance from Idaho town of same name	Location	Approximate year abandoned	Date fenced against livestock [1]	Soils	Topography	Vegetation at time of fencing
Burley	2 miles south, 5 miles west.	SE 1/4 SE 1/4 sec. 32, T. 10 S., R. 22 E.	1916	Nov. 24, 1930	Portneuf [2] silt loam.	Slight slope.	1/2 sagebrush, 1/2 weed hosts.
Castleford	8 miles east, 7–1/2 miles south.	SE 1/4 NW 1/4 and NE 1/4 SW 1/4 sec. 4, T. 12 S., R. 15 E.	1920	April 1931	Probably Portneuf silt loam, shallow phase.	Nearly level.	1/2 sagebrush, 1/10 annual grass, 2/5 weed hosts.
Wendell	5 miles west....	NE 1/4 NE 1/4 sec. 33, T. 7 S., R. 14 E.	1920	Oct. 21, 1930	Scabland.[2]	Broken, with rock outcrops.	1/2 sagebrush, 1/2 annual grass with weed hosts.

[1] Jack rabbit exclosures, 100 feet square, were set up in each of the plots early in the spring of 1932; and larger exclosures, 200 by 400 ft., in the fall of 1936 in the Castleford and Burley plots. The entire Burley plot was fenced against jack rabbits on June 1, 1938, and the Castleford plot on Oct. 1, 1944.

[2] Soil types as given in the soil surveys of the Minidoka (*15*) and Gooding areas (*16*), respectively.

so that in succeeding years records were obtained on the same soil area. The location of each sampling point was determined the first year by measuring with a tape 10 meters diagonally northeast and southwest from each large stake. That made two sampling points, or two of the 1/16-square-meter quadrats in each 100-foot square. As mentioned later under exclosures, the number of samples was doubled where the areas to be compared were small. The plants within the metal sampling frame were counted up to 25 for any species. Because of the difficulty and labor involved, species with a greater density were recorded as +25.

Both of these methods are adequate for the main purpose here—to follow general trends of the changes in plant cover. Both have definite limitations. It seems obvious that no one method can give a precise picture of the vegetation for a particular year by a single illustration or by a single determination, since some changes take place during the growing season. Thus, both methods fall short where plants are being clipped by jack rabbits—the area may be under fair cover in the early part of the season and yet bare late in summer and in fall. Again, in a particular year Russian-thistle seedlings may be abundant in a downy chess cover and die prematurely early in summer. The sampling method would overemphasize in that season the importance of Russian-thistle and the visual-estimate method disregard it. The same applies when seedlings of a perennial grass are very numerous but inconspicuous. In some years Russian-thistle may appear in a downy chess cover as scattered large well-developed plants, as in 1936. These plants, few in number, may escape recording by the sampling method but not by that of visual estimate. In a detailed study of the plant cover many such instances would be taken into account, but here the discussion is limited largely to the general trends of the changes.

CHANGES IN VEGETATION WITH AND WITHOUT EXCESSIVE DESTRUCTION

An ideal set-up would be to determine the maximum rate of change of vegetation with no destruction by any cause and then to compare with this the results from varying degrees of destruction, particularly uniform rates of destruction in successive seasons throughout the period of studies. During these studies the purpose was to determine why the changes leading to a downy chess cover did not take place in particular situations and what corrections, if any, might be made to bring about the desired changes. Prevention of destruction here, therefore, was aside from the main purpose and was carried out only to the degree thought necessary to induce the plant successions. The satisfactory uniformity achieved in this respect was not paralleled in the areas intended for contrast, and the desired excessive destruction extending uniformly throughout the period is not available. There is instead great variation; however, the partial contrast of a long retarding or delay of the successions by the temporary excessive destruction is shown.

The results are dealt with in three sections. In the first, the changes (1932-37) on the small areas, closed to both livestock and jack rabbits, are contrasted with the changes on the 20-acre weedy part of the plot, closed to livestock and open to the feeding of jack rabbits. The small areas referred to as areas free from excessive destruction were uniformly maintained in that status throughout the period. The 20-acre areas varied greatly in the vegetation destroyed. In the second section (1937-44) similar comparisons are made at Burley and Castleford but with larger areas (jack rabbit exclosures), which again are maintained uniformly free of excessive destruction, whereas on the areas open to jack rabbits excessive destruction decreased beginning in 1939 and became negligible by 1941. Thus, conditions for inducing the development of a downy chess cover were maintained throughout, whereas the extent of destruction varied greatly. The third section deals with the deterioration of a plant cover, followed by soil erosion, where vegetation was exposed to excessive destruction by jack rabbits or by livestock and jack rabbits.

To keep out livestock, 39-inch sheep fence was used. When rabbits also were to be excluded, poultry fencing, 1-inch mesh, 24 inches wide, was

fastened on the outside of the stock fence. For excluding jack rabbits from the small areas within the livestock fence, the 24-inch poultry fencing alone was used with a strand of barbwire above it.

Changes in 1932-37

The changes here pertain to areas all of which were free from grazing by livestock. The difference is that areas of the first group dealt with were exposed to the feeding of jack rabbits and the second were not. Areas of the first group suffered slight to excessive destruction of vegetation by jack rabbits, whereas those of the second were uniformly free from any noticeable destruction of vegetation from any cause.

TWENTY-ACRE WEEDY PART OF PLOTS

The areas dealt with here were free from all grazing by livestock but exposed to the feeding of jack rabbits. The results shown in figure 3 are visual estimates. The figure is simplified by showing only the percentage of the areas covered by downy chess, since the main point here is to see to what extent progress was made toward a complete downy chess cover in each of the plots. The rest of the area was occupied principally by Russian-thistle and two mustards, flixweed and tumblemustard. The relative proportions of the various constituents of the vegetation within the plots were later shown by the sampling method.

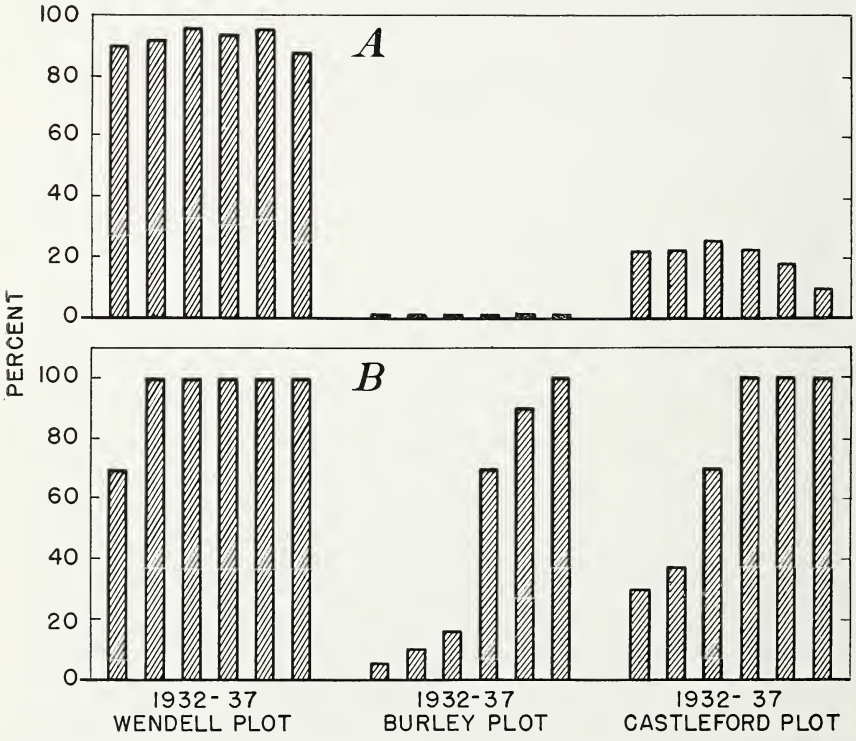

Figure 3.—Percentage of area covered by downy chess: *A*, On the 20-acre weedy part of the plots closed to livestock but exposed to the feeding of jack rabbits, there was no common trend and no progress toward a downy chess cover. *B*, On small 100- by 100-foot areas closed to both livestock and jack rabbits, there was a common trend that ended with a downy chess cover.

Of the three tracts, the cover at Wendell was the most uniform for any particular year and also throughout the period. The prevailing type at the outset was downy chess, which persisted in the succeeding years and varied only in the extent of the admixtures of Russian-thistle or mustards. The admixture was large in 1936, when there were 100 to 400 Russian-thistle plants per 100-foot square. The plants grew large and covered an estimated 10 to 25 percent of the downy chess area.

At Burley, unlike Wendell, the weed hosts tumblemustard and Russian-thistle formed the principal constituents of the vegetation at the outset (fig. 3, *A*) and maintained this status throughout the period, varying only in proportions, whereas downy chess did not form any measurable part of the cover at any time.

The plant cover on the Castleford plot showed the greatest extremes and differed markedly from both the others. At the outset there was less uniformity than on the other two plots. One part (about 20 to 25 percent) was occupied by downy chess (fig. 3, *A*), and, though its boundary fluctuated somewhat and the admixtures of mustards varied, it remained almost as unchanged as the cover at Wendell for the period 1931-35. Deterioration, however, began in 1936 and, as seen later, continued through 1938 and 1939. The remaining part was largely covered by weed hosts (Russian-thistle, tumblemustard, and flixweed) of varying mixtures and densities, and in some years when sparse stands were destroyed there was severe soil erosion.

In summary, then, on the 20-acre areas protected from grazing by livestock, but subjected to the feeding of jack rabbits, the trend or course of the changes on any one plot was unlike that of the others.

SMALL AREAS CLOSED TO BOTH LIVESTOCK AND RODENTS

The areas dealt with here were uniformly free of excessive destruction of vegetation from any cause. They were 100- by 100-foot jack rabbit exclosures situated, one in each of the plots, at the ends of strips plowed in the spring of 1931 and kept clean of all plant growth during that season. These strips, including the small exclosures, were equal in that they contained no perennials and were free of any previous development that may have taken place in the vegetation of annuals in previous years. As discussed later, the small exclosures were not equal in the nearness to downy chess areas and in the possibility of an influx of a large quantity of seed.

As the original purpose of the small exclosures was to protect plantings, the results dealing with changes in vegetation were incidental to that purpose. Approximately half of each of the exclosures was used for plantings consisting either of perennial grasses or of annual weeds. Thus, in each exclosure seed was introduced to produce an initial area of each of the annual weeds, including downy chess.

The development of the plant cover on the parts of the exclosures open to the invasion of the annual weeds, or rather the parts not occupied by the planted perennials, is shown in figure 3, *B*.

The changes at Wendell, where downy chess surrounded the exclosure, were most rapid, and there was a general cover of downy chess the second year and thereafter. The other weeds still appeared in varying admixtures, particularly in 1936, when there was a scattered stand of Russian-thistle. In contrast, the downy chess cover developed slowly in the Burley exclosure, where there were no downy chess areas nearby. At Castleford, where the exclosure bordered a downy chess area on the east side (fig. 4), the length of time was intermediate between the two. This difference in the rate of development of a downy chess cover was attributed to a heavy influx of seed from a nearby source at Wendell, and, to a less extent, at Castleford.

At Wendell the part of the plowed strip (not included in the exclosure) that was flanked on two sides by downy chess showed a development similar to that within the exclosure, and in 1933 and 1934 it was barely distinguishable from the rest of the plot. At Castleford and Burley the changes on the strips were unlike those of the exclosures and became more and more like the rest of the plot. After some preliminary changes, each of these plowed strips, closed to livestock and open to jack rabbits, resembled in plant cover the particular 20-acre area in which they were situated.

FIGURE 4.—The Castleford small jack rabbit exclosure shows as a light-colored square (center), with a good cover of downy chess, except for the plantings of perennials. In the foreground (left) is sagebrush, and at the right, bordering the exclosure on three sides, is a dense growth of Russian-thistle. The light-colored field to the east of it (above) is also downy chess, except for an irregular sparse patch of Russian-thistle near the fence. (Sept. 22, 1939.)

Summarizing: At Castleford, Burley, and Wendell the development of the plant cover was alike in all three small exclosures where there was never excessive destruction of vegetation from any source. In each case the development ended in a downy chess cover (fig. 3, *B*). On the three 20-acre areas, where livestock was excluded but the vegetation was subjected to a varying degree of destruction by jack rabbits, the changes were not alike in any two of the three (fig. 3, *A*). At Wendell the plant cover remained nearly static. There was a fluctuation from one to the other of the weed hosts, without a definite trend at Burley, and a deterioration in cover and severe soil erosion for most of the area at Castleford.

CHANGES IN 1937-44

In 1936, when the differences between the small exclosures and the rest of the plot became evident, it seemed desirable to check the results with larger exclosures and with places where no plantings of any kind were made. Accordingly, the large exclosures (200 by 400 feet) were set up within the Castleford and Burley plots late in the fall of 1936. Construction of a new highway mutilated the Wendell plot, and it was later dismantled and the studies there were discontinued.

The studies for the period 1937-44 at the Castleford and Burley plots differ in their nature, and the results are dealt with separately.

AT CASTLEFORD PLOT

Comparisons are made here among equivalent areas, all of which are closed to stock; the difference among them is that the 200- by 400-foot area is also closed to jack rabbits. The jack rabbit exclosure was so placed within the Castleford plot as to cover part of the erosion area and consisted of an area of bare soil, roughly one-third; an area of low hummocks of drifted soil with patchy vegetation on the mounds, somewhat less than one-third; and an irregular area of a fair cover of weeds, slightly more than one-third, where erosion in the preceding winter was slight.

The general progress toward a downy chess cover can be shown by visual estimates. Thus, within the exclosure free from jack rabbits and from excessive destruction of vegetation by any cause there were only a few colonies of downy chess present at the beginning (1937) and the total area covered was estimated at approximately 4 percent; in 1938 this increased to 13 percent; in 1939, to 23; in 1940, to 58; and in 1941, to 98. The vegetation outside the exclosure and exposed to the feeding of jack rabbits was different initially at the south and west from that to the north and east, so that in making comparisons of equivalent areas outside the exclosure both areas were used. In neither of these was there a measurable area covered with downy chess until 1941, when it became an important constituent on the north and east sides, though not a dominant except in small colonies (less than 5 percent).

The less marked changes in the vegetation and in the relations of the various constituents are better shown by the sampling method (fig. 5). Here the inside of the exclosure is compared with the two equivalent areas outside already mentioned. Since the areas are relatively small (200 by 400 feet each) the number of samples was doubled, making a total of 32 for each area.

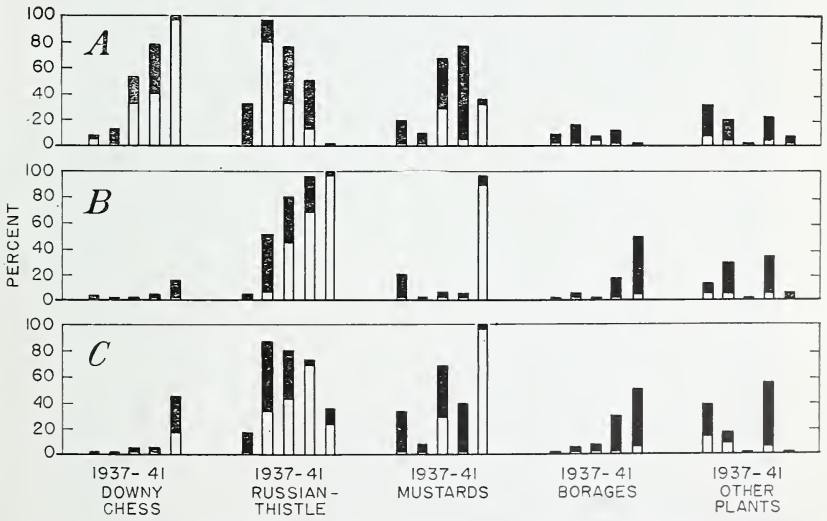

FIGURE 5.—Percentages of the samples containing the various species of plants in three areas, all closed to livestock and within the Castleford plot. The area *A* lies within an exclosure not open to jack rabbits. Two areas are outside the exclosure, open to jack rabbits—one adjacent to the exclosure on the south (*B*) and the other on the north (*C*). The unshaded part of the bars shows percentages of samples containing 10 or more plants.

In figure 5 the percentages of the samples that contained each of the various constituents are charted, also the percentages that contained 10 or more plants of each. The first shows distribution, and the second gives some measure of distinction between sparse and dense stands.

FIGURE 6.—Vegetation on the Castleford plot at the end of the first growing season after fencing on a part of the weedy area closed to livestock but open to jack rabbits, within which lies the exclosure (oblong center) closed to both livestock and jack rabbits. Beyond (south of) the exclosure the ground was bare and wind-swept except for a few scattered Russian-thistles. The initial Russian-thistle numbers on the north side of the exclosure (middle foreground) were about equal to those within but decreased as the season progressed. The smaller growth in the northwest corner of the exclosure (extreme right) is composed of cutleaf nightshade and tumbleweed. A corresponding growth outside the exclosure was annihilated by the jack rabbits, leaving only a few scattered and deformed Russian-thistle plants. Downy chess colonies show as light patches near the south (upper) end of the exclosure both at the middle and at the extreme left. (Aug. 13, 1937.)

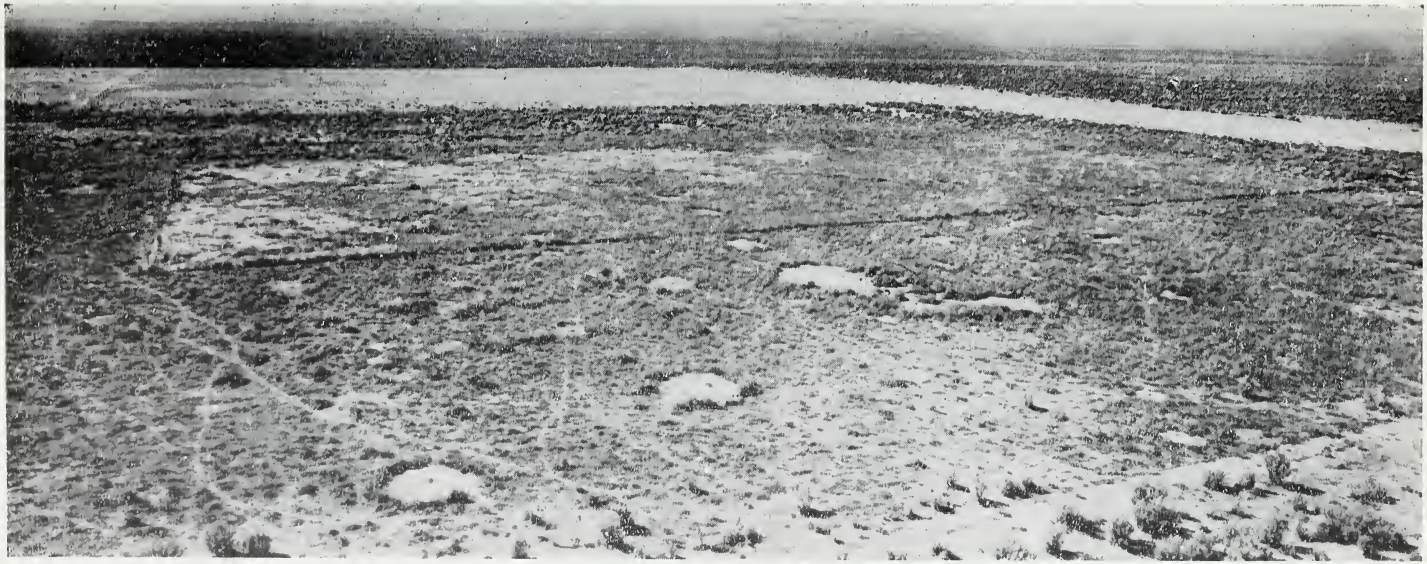

FIGURE 7.—By 1939 the downy chess colonies on the Castleford plot (light-colored areas) shown in figure 6 had expanded to approximately one-fourth of the area of the exclosure (oblong center). The growth of Russian-thistle outside the exclosure had greatly increased, and the bare wind-swept part on the south side (light area above) had been reduced. The main jack rabbit trails lead around the lower left corner of the exclosure. Those going directly south (middle foreground) and west (right) are faint and little used. Flixweed is a prominent admixture in the Russian-thistle in the exclosure but is lacking outside, except on the north (middle foreground.) The circular clearings (foreground) are made by old ant hills. (Sept. 22, 1939.)

Downy chess showed a steady development within the exclosure (fig. 5, *A*), until by 1941 it occurred in all the samples and with more than 10 individuals in each (all but 1 had more than 25 plants). On the south side (fig. 5, *B*), downy chess showed no development until 1941 and then it was slight. On the north side (fig. 5, *C*), the development was somewhat greater in 1941, but there was practically none before then.

Russian-thistle inside the exclosure (fig. 5, *A*) developed to a peak in the second year, then dropped away until in 1941 it did not occur in any of the samples. On the south side (fig. 5, *B*) it reached its greatest development more slowly and not until 1941; on the north side (fig. 5, *C*) it developed more nearly like that within the exclosure but its decrease was slower. In 1941 it still occurred in about one-third of the samples and there were 10 or more plants in about one-fourth.

Mustards (chiefly tumblemustard or flixweed and rarely green tansymustard) became important constituents in the third or fourth years (fig. 5, *A*), though they continued in 1941 in about one-third of the samples with 10 or more plants. On the south side (fig. 5, *B*) there was practically no increase until 1941, when they became about coequal with Russian-thistle. On the north side mustards increased more gradually and in 1941 were dominant; they were much more abundant than Russian-thistle, and to some extent they contained an admixture of downy chess.

Borages included chiefly stickseed and nievetas, with a small proportion of *Pectocarya* and rarely *Cryptantha circumscissa*. These were at no time important constituents in the dense covers within the exclosure (fig. 5, *A*) and were lacking in 1941. Outside, both on the north and the south, where in general the covers were sparse, the borages increased until in 1941 they were fairly widespread.

Other plants included chiefly tumbleweed and cutleaf nightshade, with smaller proportions of prickly lettuce, redscale, narrowleaf goosefoot, and rarely *Monolepis nuttalliana* (Schult.) Greene. The first two were much more abundant than the others outside the exclosure, but inside only for the first 2 years. The percentage shown for 1940 (fig. 5) was caused by sweetclover seedlings, but these did not survive in the dense cover. In a generally sparse cover in 1938, scattered plants of sweetclover grew to maturity and produced seed. The same year prickly lettuce and even a few wheat plants from stray poisoned kernels flowered and produced seed, but the occasional seedlings that appeared outside the exclosure were soon clipped by jack rabbits and none grew to maturity at any time.

Two phases of the development within the large exclosure and of the partial recovery outside of it are shown in figures 6 and 7.

The effect of the feeding of jack rabbits is best shown in the first year of protection. Early in the season the numbers of plants to the sample area on the north side of the exclosure (and open to jack rabbits) were slightly higher than the numbers within, but by July the positions were reversed as the plants outside were eaten off (fig. 8, *A* and *B*). A recount made on September 15, 2 months after the first count, showed a mortality of 8 percent within the exclosure, whereas the areas open to jack rabbits showed a mortality of 88 and 93 percent, respectively, on the south and north sides. Although this mortality included practically all species, it was highest with tumbleweed and cutleaf nightshade, the two most numerous species in the sparse cover on the previously eroded part. Russian-thistle was next highest. Survival of the plants inside the exclosure resulted not only in a greater number of plants but also, since the plants were not clipped but were well-developed, in a greater density of cover. Individual plants or small colonies of downy chess were clipped up to the exclosure fence (fig. 9). During the time that the plot was protected against livestock only (1931-37), there was no development of a downy chess cover. In fact, the particular area later included in the jack rabbit exclosure had undergone erosion and was sparsely covered or with nearly bare soil; but as soon as protection was given against jack rabbits as well as livestock, the development of a downy chess cover began, and it was completed in 5 years. This supports the findings in the small exclosures, and the rate of the development is the same as that near Hollister (*9*).

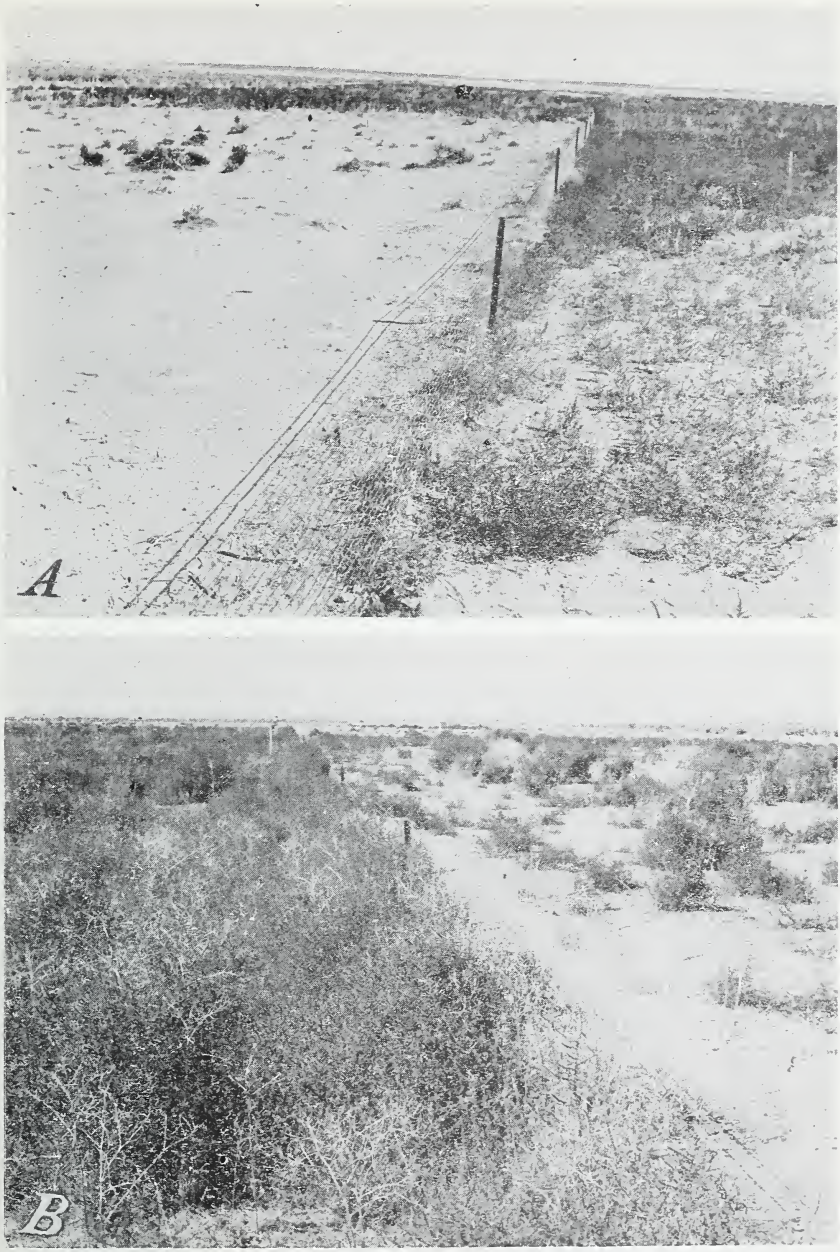

FIGURE 8.—Two views of the north side of the jack rabbit exclosure within the Castleford plot. *A*, Looking east from the northwest corner; initially the stands were about equal, but left of the fence the plants were destroyed by jack rabbits. *B*, At the opposite corner (northeast); within the exclosure (left) the large Russian-thistle plants form a dense cover, whereas outside, the plants are few and many are deformed by constant clipping. (Oct. 6, 1937.)

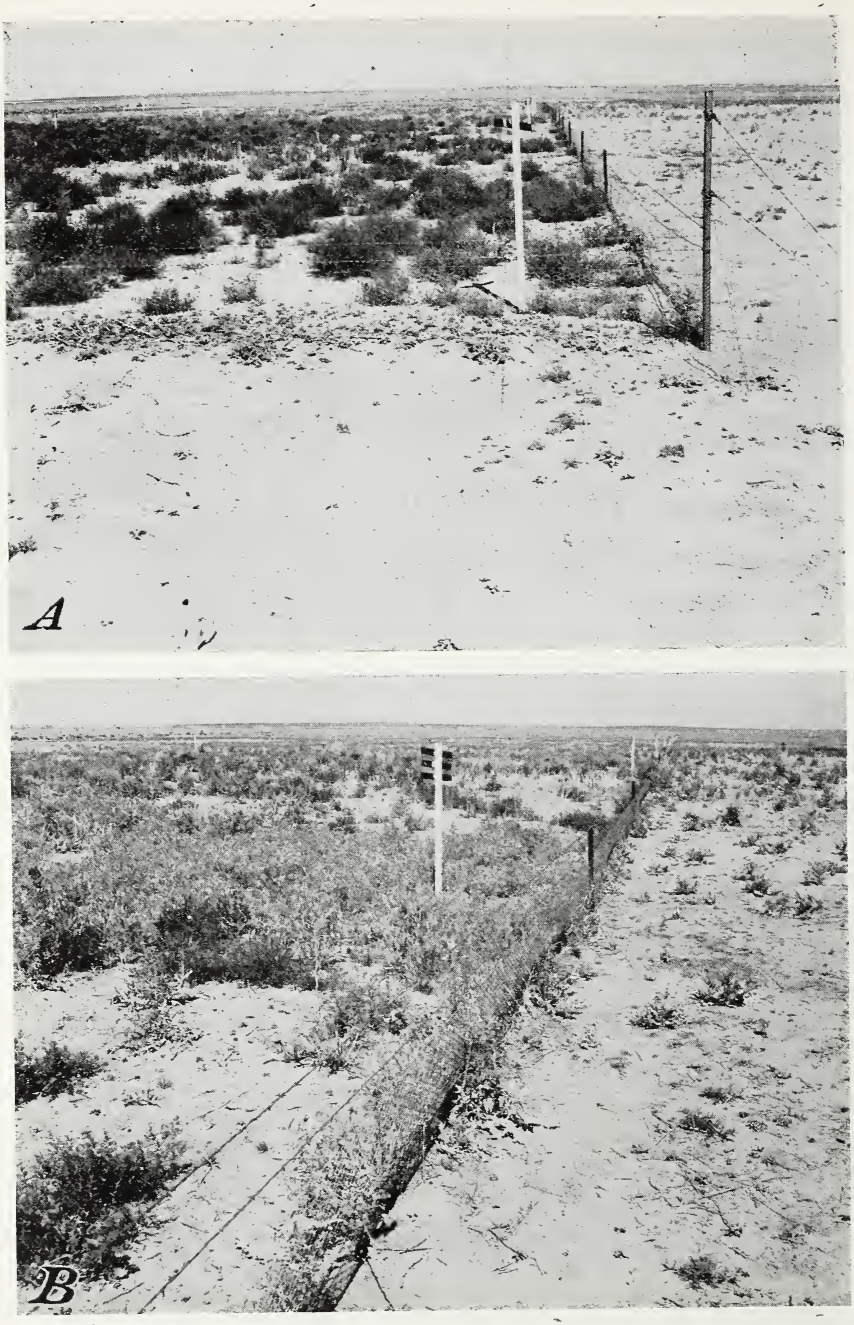

FIGURE 9.—*A*, The southeast corner of the jack rabbit exclosure within the Castleford plot. The outside stand has been almost entirely destroyed. *B*, The south fence of the same exclosure cut across a downy chess colony. The part of the colony inside (left and surrounding the 5-foot stake) thrived and grew to maturity, while that exposed to the feeding of jack rabbits (right) was completely destroyed. The rest of the plants, tumble-mustard and Russian-thistle, were mostly clipped and deformed. (June 29, 1937.)

The development of a downy chess cover for the entire weedy half of the plot for the period 1938-44 is shown in figure 10. Each dot represents the presence of downy chess within a sample area (1/16-square meter). The figure is based on 130 samples for each year, and each sample area is marked by pegs so that throughout the period the data were obtained on the same areas.

Some of the limitations of this method have been discussed previously (see Determining Changes in Vegetation, p. 13. Thus, in 1944 (fig. 10) mustards were represented by seedlings, few of which matured or became conspicuous except for a narrow strip at the right. So, too, in 1944 Russian-thistle matured and was a dominant only in a small area in the upper right corner, approximately equivalent to the area unoccupied by downy chess in 1944 (fig. 10).

The general trend in the weedy half of the plot is seen in figure 10, if followed from left (Russian-thistle) to middle (mustards) and then to right (downy chess). There is evident the general Russian-thistle cover at the beginning of the series and its decline, followed by one of mustards in the middle of the series, and finally the one of downy chess.

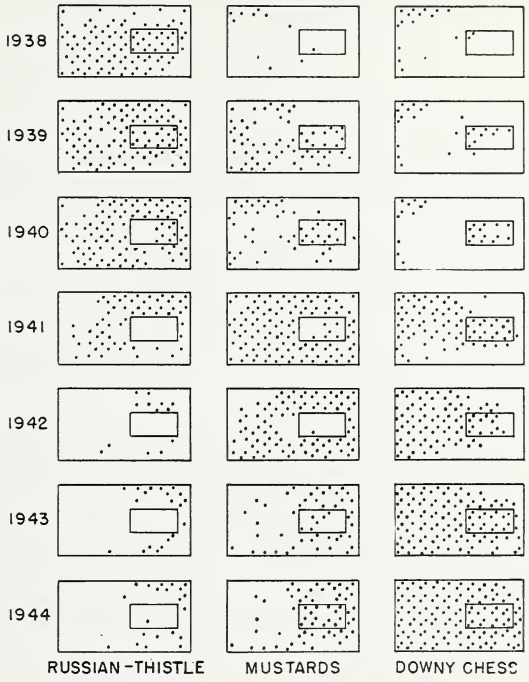

FIGURE 10.—Development in a vegetation of annuals on the 20-acre weedy part of the Castleford plot (1938-44). Each dot represents the occurrence of the particular annual in a sample, based on 130 samples (1/16-square meter) each year. The decline of a Russian-thistle cover is followed by a cover of mustards and these in turn by downy chess. The entire area was closed to livestock throughout the period and open to jack rabbits except for the exclosure (rectangle at right). The development of downy chess within the exclosure took place in 5 years, that in the rest of the 20-acre area only after destruction of vegetation by jack rabbits became negligible and after a total of 14 years from the time of fencing against livestock (1931).

If the time since fencing (1931) and the data in figure 3 (1932-37) are taken into consideration, as well as figure 10 (1938-44), then the downy chess cover (in the total area free from livestock but open to rabbits) has reached its present status in 14 years. But during this time a downy chess cover had developed at two different periods and on two different areas where rabbits as well as livestock were excluded—the small exclosure (fig. 3) and the large exclosure (fig. 5). In the weedy half of the plot (fig. 10) the downy chess cover developed only after the destruction of vegetation by jack rabbits became negligible. This last was obvious by the absence of clipping, of trails, and of pellets and is attributed to the great decrease in numbers of jack rabbits beginning in 1939.

Unlike the Burley plot, there was no development of a cover of native perennials here. They were few in number at the beginning and continued

so throughout the period 1931-44. In 1944 perennial grasses occurred in 2 of the 130 samples and sagebrush also only in 2. An estimate of the tufts of perennial grasses (squirreltail and Sandberg bluegrass) was a range of 1 to 5 tufts for each 100- by 100-foot square. The entire Castleford plot now (Oct. 1944) is fenced against jack rabbits as well as livestock. It remains to be seen whether, considering the few tufts of perennial grasses present, the perennial grass cover will develop in spite of the meadow mice harbored by the dense growth of downy chess.

AT BURLEY PLOT

As shown previously (fig. 3), during the period 1932-37 the changes in vegetation in the weedy part within the livestock fence of the Burley plot consisted of a fluctuation between Russian-thistle and mustards, with first one and then the other as a dominant. There was a scattering of perennial grasses in parts of the weed cover, but the tufts were too few and too devitalized by repeated clipping by rodents to have any appreciable effect on the vegetation during that period. In the fall of 1936 the 200- by 400-foot jack rabbit exclosure was so placed within the plot (livestock) fence as to include a scattering of perennial grasses at the east end. The rapid recovery of the perennial grasses prompted the exclusion of rabbits from the entire 40-acre plot in June 1938. While this gave a much better opportunity to observe the spreading of the grasses over a large area, it shortened the period within which contrasts might be expected between the inside of the exclosure and an equivalent adjacent area.

The poultry netting placed around the Burley plot in 1938 immediately prevented invasion of rabbits from nearby areas but did not immediately prevent damage to vegetation, because a considerable number were incidentally enclosed within the fence. Most of these were exterminated, however, during 1938. The comparatively few that persisted in 1939 and 1940 did very slight damage to the vegetation. Damage to vegetation from rabbits, then, can be considered as moderate in 1938 and negligible in subsequent years.

For the entire 20-acre weedy part of the Burley plot the development of the vegetation of annuals and also of the next stage, perennial grasses, is shown in figure 11 for the period 1938-44. The figure is based on 185 samples, each dot representing the presence within the sample of the particular kind of annual or perennial indicated. Here again, when excessive destruction of vegetation ceased, that is, when jack rabbits as well as livestock were excluded, there was rapid development to a downy chess cover, which had not taken place up to 1937 (fig. 3). Beginning in 1938 (left, fig. 11), with a plant cover chiefly of Russian-thistle, this gave way to mustards and then to downy chess. In this area downy chess started its development at a very low point. It was present in only 3 samples of 185 in 1933; in only 1 or 2 samples in the other years (1934-37); and for this period the total number of individuals in the samples ranged from 1 to 6. Perennial grasses increased rapidly after jack rabbits as well as livestock were excluded. They formed a principal part of the cover by 1944. This is discussed more fully at the end of this section, p. 27.

The proportions of the various constituents of the plant cover (other than perennials) are shown in figure 12. Comparison is made of the 20-acre weedy part of the Burley plot closed to both livestock and jack rabbits with an area outside of the plot open to both. Inside the plot the annual grasses downy chess and sixweeks fescue are subordinate in the first years, and Russian-thistle, mustards, and, to a less extent, borages are predominating, whereas the grasses are the dominants in the later years and the other annuals tend to disappear. To a lesser extent the same trends are evident in the area outside the plot; the development of a grass cover is less pronounced, and the other annuals maintain a higher proportion in the later years. Here, as at Castleford, there is the beginning of a development of a downy chess cover, which is attributed to the great decrease in jack rabbits beginning in 1939 and consequently to the comparatively slight destruction of vegetation by them between 1941 and 1944.

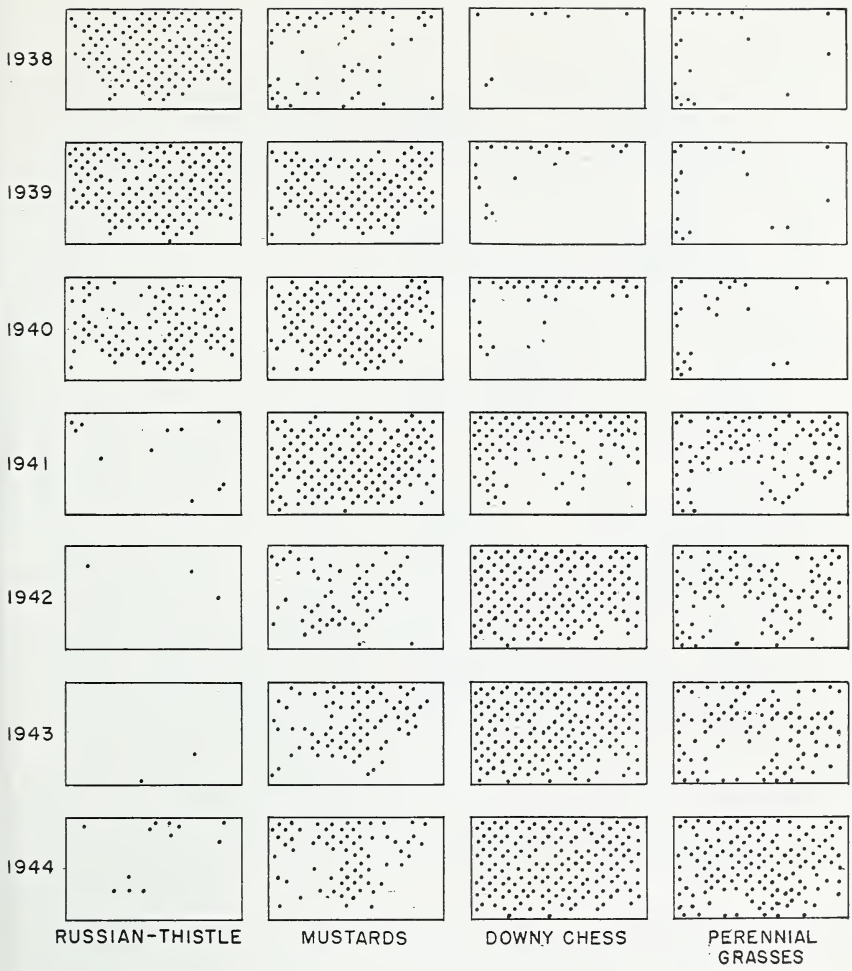

FIGURE 11.—Development of a plant cover on the 20-acre weedy part of the Burley plot. Each dot represents the occurrence of the particular annual weed or perennial grass in a sample, based on 185 samples (1/16-square meter) each year. Beginning at the left, the Russian-thistle cover declines, is followed by mustards, and then in turn by downy chess. Perennial grasses at the right show a slower rate of development contemporaneous with the downy chess cover. The entire area was closed to both livestock and jack rabbits for this period (1938-44), and there was no excessive destruction of vegetation by any other cause.

The part that perennial grasses took in the development of the plant cover within the plot (closed to both jack rabbits and livestock) and the spreading of the perennial grasses was shown in figure 11. The development of the perennial grass stage was contemporaneous with that of downy chess. The general trend of these two and also of sagebrush is shown in figure 13 for the entire period 1933-44, and the same is shown in figure 14 for the area outside of the plot (exposed to both livestock and jack rabbits). For the period 1933-37 the general trends are much the same in the two areas as long as

there was excessive destruction inside of the plot by jack rabbits and outside by jack rabbits and livestock.

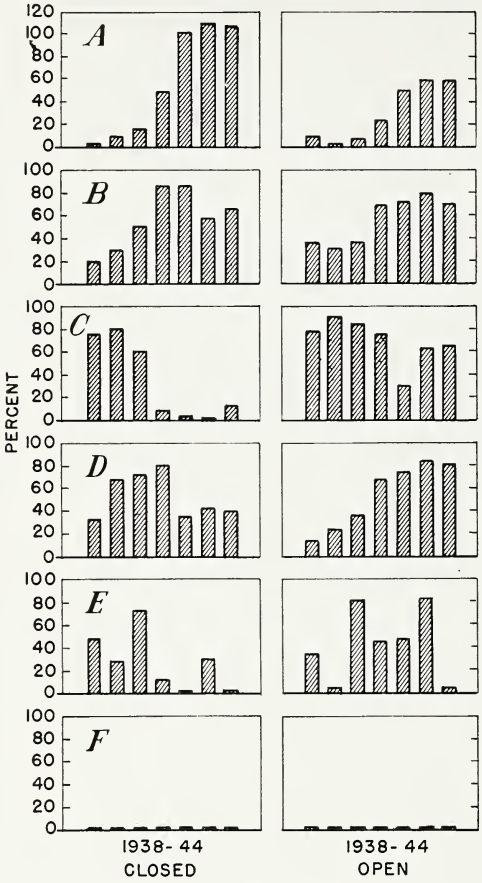

FIGURE 12.—Comparisons of percentages of samples containing the various annuals (*A*, downy chess; *B*, sixweeks fescue; *C*, Russian-thistle; *D*, mustards; *E*, borages; *F*, other annuals) on two areas, 1938-44: Left, the 20-acre weedy part of the Burley plot (closed to both livestock and jack rabbits); and right, outside of the plot (open to both livestock and jack rabbits).

After 1938, when destruction of vegetation within the plot became negligible, the increase in both downy chess and perennial grasses was marked. Outside the plot, with the decrease in jack rabbit numbers beginning in 1939, there was comparatively slight destruction of vegetation from 1941 to 1944 and there was development of a downy chess cover, though not so marked as inside the plot. Perennial grasses showed little change.

Although the results are not wholly satisfactory, because no area is available for comparison where excessive destruction of vegetation is continued throughout the period, nevertheless some significant contrasts can be made. Outside the plot (exposed to both livestock and jack rabbits) there was only a partial development of a downy chess cover in the 12 years (fig. 14) and no increase in perennial grasses. Within this period, on two different areas and at two different times, development of a downy chess cover had been induced within the plot by excluding both jack rabbits and livestock. One of these occurred in the 1932-37 period within the small exclosure (fig. 3) when on the rest of the plot and also outside the plot there was either no development or a deterioration of the cover. Again, perennial grasses in the two areas (figs. 13 and 14) started out equal, but outside the plot there was no increase, rather some decline, whereas inside, after both jack rabbits and livestock were excluded the perennial grasses formed the principal part of the plant cover.

Also, during the period 1932-37, when perennial grasses declined both inside and outside the plot as long as they were exposed to the feeding of jack rabbits, plantings of perennial grasses inside the small jack rabbit exclosure within the Burley plot thrived during the same period. The plantings included native species, Sandberg bluegrass, squirreltail, and streambank wheatgrass, as well as the introduced crested wheatgrass (fig. 15). Similar plantings of crested wheatgrass outside the exclosure and exposed to rabbits did not survive.

Since there is obviously overlapping of the annual and perennial types of cover, as shown by the percentages of the samples, a short account of the status of the vegetation within the Burley plot in 1944 will help integrate these. In much of the area covered by the perennial grasses and to some

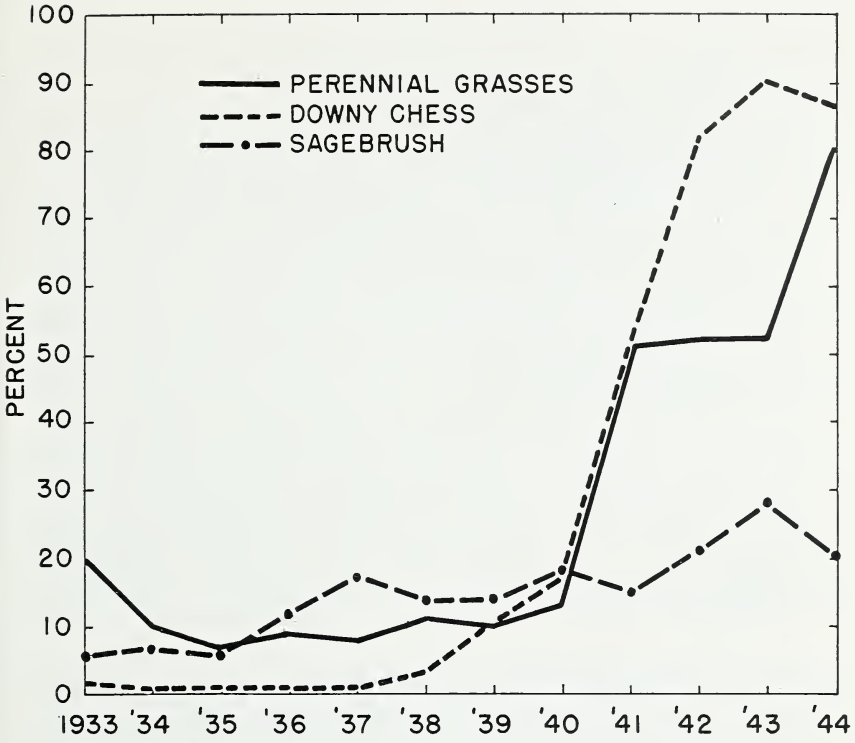

FIGURE 13.—Comparative trends (1933-44) of perennial grasses, downy chess, and sagebrush within the Burley plot. The percentages are based on the presence of the particular kind of plant in a sample and on a total of 185 samples each year. At the left (1933-38) are shown the trends when open to rabbits but closed to livestock; and at the right (1939-44) when closed to both rabbits and livestock.

extent even when they had become dominant, downy chess still occurred between the tufts. Considerable patches of perennials, however, were either free of downy chess or contained only a scattering of depauperate individuals. Of such patches of perennial grasses, those of squirreltail were the largest and most numerous, though there were many smaller ones of streambank wheatgrass. Of the annuals, downy chess still occurred in dense patches; Russian-thistle seedlings were abundant in places, but rarely matured; and mustards were widespread, but these matured to produce seed only in small colonies, chiefly around rodent burrows. A visual estimate of the area covered by all native perennials (sagebrush and perennial grasses) made in the weedy half of the Burley plot in 1944, 100 by 100 square feet at a time, showed 75 percent, which compared well with 81 percent as shown by the samples.

Of the perennial grasses, squirreltail made the greatest increase in the weedy half of the plot. Streambank wheatgrass and Thurber needlegrass were in an intermediate position; Sandberg bluegrass made the least increase, though in the half of the plot covered by sagebrush this grass made by far the greatest increase. Indian ricegrass occurred only in two small colonies. Other perennials too scattered to form any significant part of the cover but increasing in numbers are globemallow, rattleweed, fleabane, and *Calochortus* sp.

Squirreltail seems best adapted of the perennial grass species to form the next stage in the successions. It is prolific in seed production; has efficient

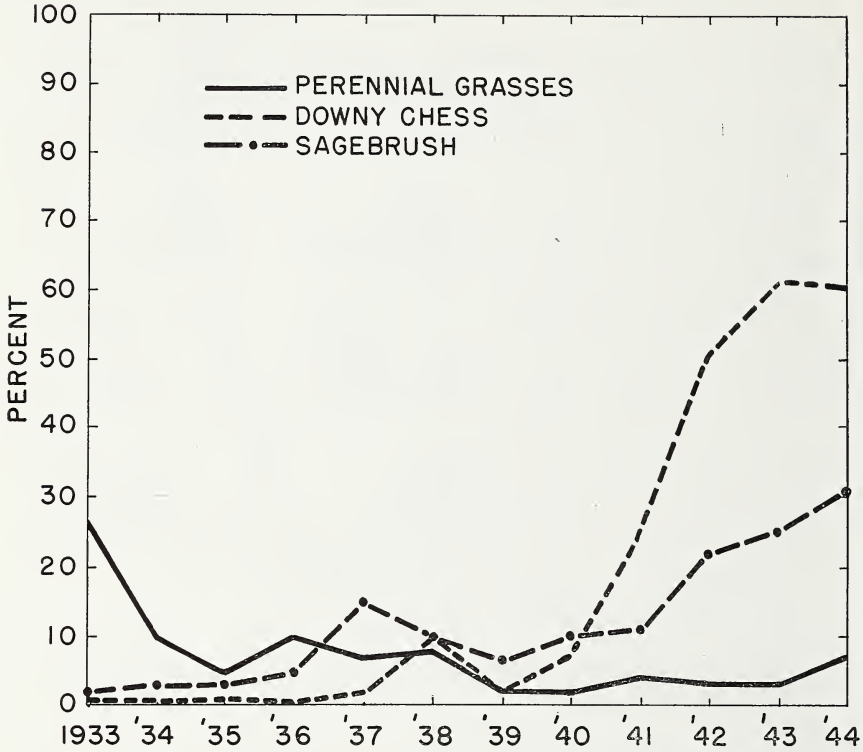

FIGURE 14.—Comparative trends (1933-44) of perennial grasses, downy chess, and sagebrush outside of the Burley plot and open to both livestock and rabbits throughout the period. Percentages are based on occurrence of the particular kinds of plant in a sample and on a total of 59 samples each year.

seed distribution, since the light heads with the long awns break up into segments that are carried readily with the wind; has seeds that germinate readily and early; and the plants mature not much later than downy chess. In its general growth habits it is similar to downy chess and has equal priority in the use of soil moisture as compared with later maturing species. It has advantages over downy chess in its more efficient seed distribution and in its perennial habit, which means that the small seedlings of downy chess must establish themselves on ground already occupied by tufts of squirreltail.

The chief difficulty in the way of squirreltail establishing itself seems to be the damage from the small rodents harbored by the downy chess cover. Destruction of the few tufts first appearing may be crucial. Once the number of established tufts becomes large, as at Burley, the destruction is limited largely to fringes of the dense downy chess patches, and this is more than offset by the large number of seedlings of squirreltail. There is at present no indication that the competition of downy chess can by itself (i.e., assuming no destruction of perennial grasses by animals) prevent development of the perennial grass stage.

The development of the perennial grass cover was at first a replacement of weed hosts, but later of downy chess as well. The development took place in the 6 years 1938-44, and assuming a similar rate, it will be completed in an estimated 8 to 9 years. The rate is judged to be slowed somewhat by the feeding of meadow mice.

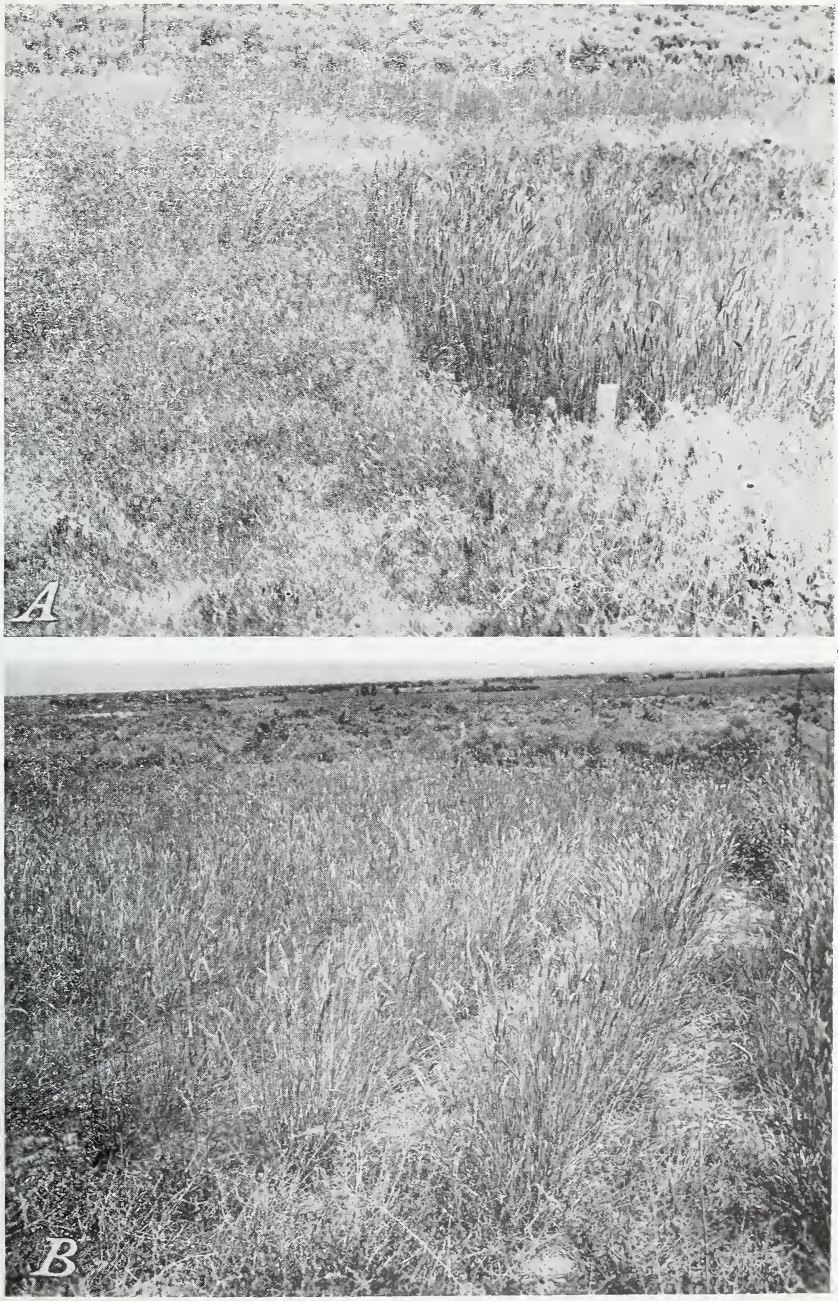

FIGURE 15.—Two plantings of crested wheatgrass within the small exclosure at the Burley plot: *A*, Crested wheatgrass (right) planted in 1934 and surrounded by downy chess. (June 6, 1938.) *B*, Crested wheatgrass planted in 1933. The spaces between the rows eventually were free of downy chess and the other annuals. Similar plantings of crested wheatgrass outside the exclosure, where they were exposed to the feeding of rodents but not to grazing by livestock, did not survive. (June 22, 1937.)

Deterioration of the Plant Cover and Development of an Eroded Area

CASTLEFORD PLOT

The Castleford plot lies at the west end of a cleared area of 240 acres surrounded by an expanse of sagebrush. At the time the plot was fenced (April 1931) a small area had been trampled at the southwest corner and was bare or nearly so (fig. 16, lowest black area at left). The bare part within the fence was small at the beginning of the 1931 season (about equal to a 100-foot square), while the bare part immediately outside was about three times that size. Nearby there were two other small bare areas at former building sites, one on a mound of excavated soil and the other on the remains of an old manure pile.

Extension of the bare areas was greatly accelerated in 1933 and 1934 and continued until 1935, when a major part of the plot (not covered by sagebrush) was bare. The greatest extent was reached in the winter of 1936-37

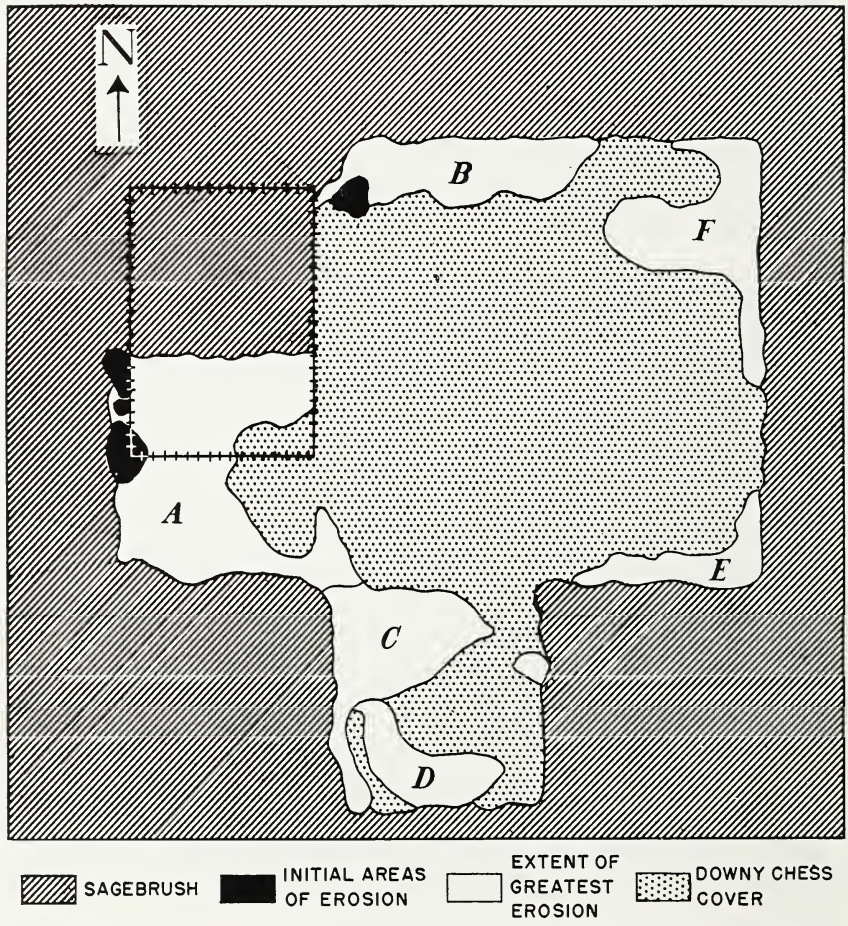

FIGURE 16.—General area surrounding the 40-acre Castleford plot (rectangle at left). All the area except that in the rectangle was open to both livestock and jack rabbits. Sagebrush, small initial areas of erosion, extent of greatest erosion, and downy chess cover are shown. Origin of bare areas *A* to *F* is discussed in the text.

(white, fig. 16). By 1938 there was a recession of the bare area, and it lay chiefly outside, south and west of the plot fence. This remained bare in 1939 (upper right, fig. 7). The central part of the general area (dotted, fig. 16) was occupied by a nearly stable cover of downy chess. Varying admixtures of Russian-thistle and mustards occurred in some years.

At the time that the bare area was extending from *A* (fig. 16), other areas in the vicinity but outside the fenced tract were increasing. The areas at *B*, *C*, *D*, *E*, and *F* had each a different origin. Those at *B* and *C* originated from heavy trampling, where sheep were bedded and fed for some time; *D* followed a burning of downy chess and subsequent grazing; the origins of *E* and *F* were not followed closely enough to ascribe any particular causes. The areas *A* and *C*, originally separate, were united and continued bare and badly wind-swept in 1938, but *B*, *D*, *E*, and *F* each had a fair to good plant cover. There was slightly more than 14 acres in *A*, and the total in *A* and *C* was about 30. Areas *B*, *D*, *E*, and *F*, with approximately 12, 6, 5, and 14 acres, respectively, totaled about 37 acres. The area within the plot fence was about 11 acres. In the winter of 1936-37 then, about 80 acres was bare and wind-swept, about one-third of the 240 acres cleared. By 1941, practically all the area had recovered. The plant cover was sparse in parts of *A*, but was good in all the other areas.

Some idea of the degree of deterioration of the plant cover and of the rate of deterioration can be obtained from figure 17, which shows percentages of the samples bare of all plants and also the percentages containing each of the various species. Three areas are compared, each including the equivalent of 8 squares (100 by 100 feet), or a total of 16 samples. The first (*A*) is an area where an initial plant cover of downy chess deteriorated and an eroded area developed; the second (*B*), where erosion was already under way at the beginning of these records in 1933; and the third (*C*), where a nearly stable plant cover of downy chess was maintained throughout.

Two general trends were evident, as shown in figure 17, *A*: First a deterioration and then in 1940, and particularly in 1941, a recovery. Deterioration was shown by the increase in the percentages of bare samples until all the samples were included. Downy chess decreased so that it was lacking in all samples in the last 4 years. Recovery was shown in the increase in Russian-thistle from 1940 to 1941, when it became the dominant and mustards became a subdominant. Temporary increases were shown in other years, mustards in 1936 and borages in 1935. Although these species were fairly widespread in the 2 years, the vegetation was sparse and the samples rarely showed 10 or more plants, whereas the increase of Russian-thistle in

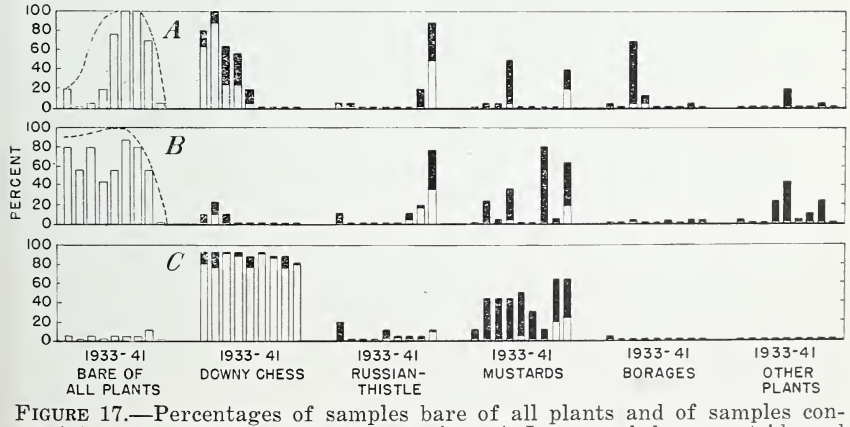

FIGURE 17.—Percentages of samples bare of all plants and of samples containing each of the various plant species: *A*, In an eroded area outside and south of the Castleford livestock fence that was covered with vegetation at the beginning of the record, 1933; *B*, west of the stock fence where an eroded area was already under way in 1933; *C*, southeast of the plot where there was a nearly stable cover of downy chess throughout the period. The unshaded part of the bars shows percentages of the samples that contained 10 or more plants each.

1941 showed that half the samples contained 10 or more plants. Where the vegetation was sparse in this area there was little protection for the soil, since few of the plants survived the growing season and the soil was bare or nearly so during late summer, fall, and winter. If this is taken into consideration, the increase in the extent of bare soil is better shown by the dotted line (fig. 17, *A*), though the general trend remains the same.

The increase in the percentage of samples bare of all plants was not so marked (fig. 17, *B*), since erosion had begun in this area in 1931 and was well under way by 1933. There was the same tendency here as shown in figure 17, *A*, for there was a recovery in 1940 and 1941, due chiefly to Russian-thistle, though mustards became a subdominant in 1941. Downy chess played no important part in this area. While mustards in 1939, and to a lesser extent other plants (chiefly cutleaf nightshade and tumbleweed) in 1937, were widespread, they became unimportant when only the samples containing 10 or more plants were considered. With respect to sparse stands, the same is true here as in figure 17, *A*—they largely disappeared, so that for the greater part of the year the soil was unprotected (dotted line, fig. 17, *B*).

The purpose of figure 17, *C*, is to show how slightly dense stands of downy chess may be affected during a time when nearby areas are undergoing erosion. The slight deterioration took place at the edge of the stand and nearest to the erosion area. Downy chess remained the dominant throughout. Mustards were an admixture in varying proportions throughout the period, whereas Russian-thistle played a very minor part and borages or other plants were practically lacking.

The data in figure 17, *C*, pertain to the extreme left lobe of the downy chess area in figure 16, but are also considered to be representative of the main central section of the downy chess area. Likewise, figure 17, *A* and *B*, though obtained from data from parts of area *A* in figure 16, is considered also to represent the general trends of the changes in areas *B*, *C*, *D*, *E*, and *F*, the chief difference being in the rate of recovery. In this, *C* resembled *A*, whereas in all the other areas recovery was earlier; that is, it set in in 1938 and was complete in 1939 and 1940 instead of 1940 and 1941.

REMOTE UNFENCED TRACT

A remote abandoned field (field No. 21) is included because no fencing is involved and it is to that extent free of the interpretation that somehow the fences at the Castleford plot were a necessary condition for excessive destruction by jack rabbits. In this field destruction of vegetation by livestock is not so readily separable from destruction by jack rabbits, but this is largely offset by observations on the ground that the greatest part of the destruction came at a time when livestock was no longer in the area. The field was not the only one so affected but was one of five in the township, the Castleford plot being the only one fenced. The point is that whatever the cause that brought about the initial sparse stand of annuals it was the subsequent continuous feeding by jack rabbits that caused the final deterioration of plant cover and ended in severe soil erosion.

This old abandoned unfenced field (No. 21), on which severe soil erosion also took place, was situated in the midst of a large sagebrush area approximately 2½ miles from the Castleford fenced tract. The general history of the field is as follows: In 1929 and 1930 there was a downy chess cover with an admixture of mustards and a scattered stand of Sandberg bluegrass; in 1931 and again in 1932 a heavy downy chess cover was burned. In 1933 there was very little early-spring growth except for a scattered stand of Sandberg bluegrass, though later in the season there was a sparse growth of Russian-thistle. This was the beginning of the bare area. It increased through 1936, and in the winter of 1937 and 1938 the blowing of soil had become so pronounced that it blocked the trail to the Castleford fenced tract (fig. 18).

The original cleared area of field No. 21 was 240 acres, of which approximately 72 acres had been covered with a growth of young sagebrush. The two white areas in figure 19 showing the most severe erosion covered approximately 92 acres. They were bare and wind-swept. On the area of moderate erosion (dotted, fig. 19) there was a varied and scattered growth (approximately 76 acres) of tumblemustard and rattleweed, which disappeared by summer, and the area was wind-swept in fall and winter. The total area

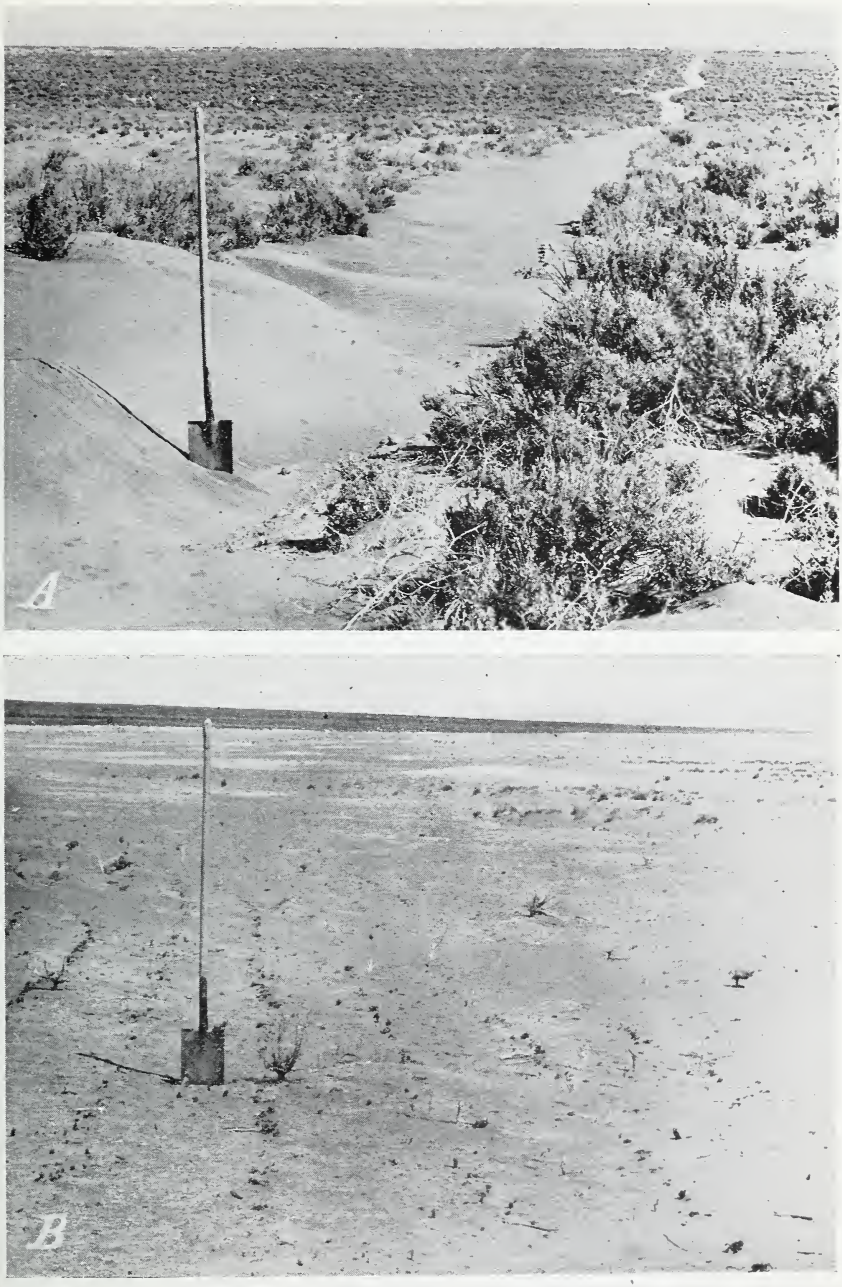

FIGURE 18.—*A*, Wind erosion of field No. 21, result of burning, grazing, and subsequently of continuous feeding of rabbits on a sparse cover. The coarser soil material lodged behind sagebrush that lined the road. The drifts were 2 to 3 feet deep and extended with lessening depth for 200 to 300 feet into the sagebrush at the right. *B*, Part of field No. 21. Near the shovel 3 to 4 inches of soil had been removed and about 6 inches in the light patches in the background. The rows shown are old stumps of alfalfa that had been buried for about 20 years and were so decayed and friable that eventually they were carried away by the drifting soil in a large part of the field. (Apr. 25, 1939.)

showing both moderate and severe erosion was about 168 acres, or about two-thirds of the area originally cleared.

The end of active erosion here was similar to that of area *A* in figure 16, that is, about 1940; and in 1941 there was a good cover. The general trend of the changes here was similar to that shown by the samples in a deteriorating plant cover in figure 17, with the minor difference that in 1941 mustards though not dense were large and predominating on field 21.

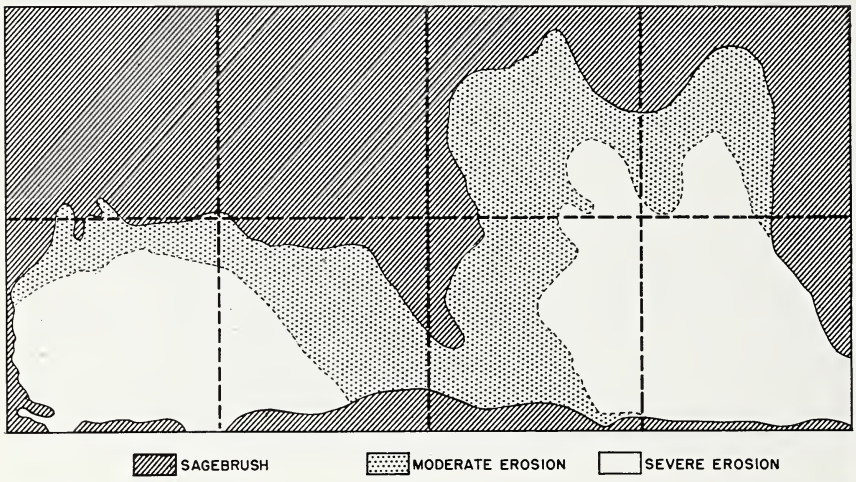

FIGURE 19.—Sketch of field No. 21, which shows the extent of severe soil erosion (white). This part of the field was bare (or nearly so) of all plants the year round. The area of moderate erosion (dotted) usually had some cover on it until summer, after which it was bare or nearly so. The sketch includes 320 acres and each square, 40 acres.

DESTRUCTION OF VEGETATION BY RODENTS IN RELATION TO THE CHANGES

Destruction of vegetation by rodents as it affects carrying capacity of western grazing lands has been dealt with by other investigators and as a main objective. In these studies the chief concern was destruction of vegetation in general and the extent to which it explained changes in vegetation. The effect of the feeding of rodents became a part of the general studies only after it was found that a downy chess cover may still fail to develop in some instances where the cause was not ascribable to plowing, burning, or excessive grazing by livestock.

The numbers of rodents are of concern here mainly where they are obvious and unmistakable, and the following notes emphasize these conditions. Largely because of lack of information, less attention is given to the possible effect of the damage by rodents, which is seemingly out of proportion to their numbers or to the volume of vegetation destroyed, because the destruction occurs at a critical time in the development of vegetation. In terms of carrying capacity this effect may be insignificant in any one season, as at present indicated in the destruction of the first-appearing tufts of perennial grasses. The effects of rodents then as to development of vegetation and as to carrying capacity may at times have a different significance. The kinds of rodents that

receive most attention here are those that had an unmistakable effect in the localities and during the period covered by the studies. It is realized that at other periods or with different vegetation other kinds of rodents may have similar significance. At least some of the rodents feed the year round and affect vegetation before and after as well as during the limited time in which livestock is on these grazing lands. The effect may not be great in any week or month and yet the total for the year may be so.

This section is meant to make for a better understanding of the effect of the destruction of vegetation—the main criterion—and is based on year-round observations as well as on the records obtained by sampling. Because the destruction caused by rodents is usually closely interwoven with that caused by livestock it is difficult to make direct application of the findings to other parcels of land, and this seems of less value than the general awareness that rodents may have a pronounced effect on the development of vegetation. This is discussed further on page 43.

Jack Rabbits

In the areas where changes in vegetation were recorded, the degree to which vegetation was destroyed was the criterion rather than numbers of jack rabbits (*Lepus* sp.). The decrease in numbers that began in 1939, however, was particularly large and general. It affected considerably those phases of the studies that were dependent on continued excessive destruction of vegetation.

In the two periods before and after the large decrease in numbers, the contrasts in the condition of soil and vegetation in the areas studied were great and unmistakable: The intense activity in the sparse stands as evidenced by the many clipped and damaged plants; the dry or often green and wilting tops strewn about; the bare soil spaces between plants greatly increasing as the season progressed and as the plants were removed; the many well-defined trails; the dusting places; fresh pellets; and the soil crust broken and churned to dust over considerable areas when livestock was no longer on the grazing lands or where livestock was excluded. Contrasted with this were similar sparse stands in the years following 1941; stands remaining intact throughout the season; no clipped plants or scattered fragments; no well-defined trails; no fresh pellets; and the thin soil crust scarcely broken anywhere after showers. The two extreme conditions were those found in the studies in such areas as at the Castleford plot or field No. 21. The detailed processes involved in the changes in vegetation under these conditions are described in table 1.

There were also local differences in destruction of vegetation by jack rabbits prior to 1939, the effects of which are shown in figure 3. Whatever the validity of the reasons given for the local differences in destruction of vegetation by jack rabbits, the essentials remain that there were such differences and that these affected the changes in vegetation.

The feeding on the weedy areas is understood to involve a movement of jack rabbits from nearby sagebrush to the weedy areas. Jack rabbits live within the sagebrush-covered areas, build their forms, make their nests, and rear their young there. By July

most of the plants in the sagebrush are cured and dry, only the shrubs, chiefly sagebrush, remaining leafy and green. The weedy areas other than downy chess are still green, and Russian-thistle, if not too dense, remains green throughout the summer. It is not clear whether jack rabbits are attracted to the weedy areas because of the greenness and palatability of the weeds as compared to the dry plants available in the sagebrush areas or whether they are forced to the weedy areas because of a general shortage of food plants due either to grazing by livestock or to a particularly dry year. Perhaps some combination of these usually operates.

Anything that would hinder the ready movement of the jack rabbits from the sagebrush to the weedy areas, as ditches and streams, would to that extent be a protection to the weedy area. The proportion of sagebrush cover to weedy areas would also have an effect, since it seems evident that a comparatively small weedy area surrounded by a large expanse of sagebrush would be used heavily by jack rabbits from the surrounding sagebrush. There are, too, the local differences in numbers. Davis (*4*) states that jack rabbits in southern Idaho fluctuate in numbers over a period of years and also from year to year and from locality to locality.

Jack rabbits were abundant in the general area represented by the plots up to 1939, but in that year and in 1940 large numbers died and carcasses were numerous throughout the sagebrush area. This was noted repeatedly on surveys of weed hosts in Owyhee, Twin Falls, and Cassia Counties. In the surveys in 1941, few jack rabbits were seen where formerly they were abundant, but north of the Snake River, in Gooding, Jerome, and Minidoka Counties, the numbers were still large and seemed more nearly comparable to those of 1939 south of the river. By 1943 and 1944 the numbers were far lower than at any time since the beginning of the studies in 1929. In 1943, items in the local papers referred to a general scarcity of jack rabbits in southern Idaho. During routine travel to the plots a considerable number would usually be seen on each trip prior to 1939. In 1944 only rarely was one seen on trips in the first half of the season and none in the last half.

The following affords a contrast in the number of jack rabbits incidentally enclosed within the Burley and Castleford 40-acre plots. On June 1, 1938, rabbitproof fencing was added to the livestock fence set up in 1930 around the Burley plot. Within a month 53 rabbits were shot, chiefly jack rabbits, but some were cottontails. Subsequent figures include any young reared within the plot. There were 41 more killed for the remainder of 1938, 11 in 1939, and 12 in 1940, a total of 64. Included in this were 2 pygmy rabbits (*Brachylagus idahoensis*) and 1 cottontail (*Sylvilagus* sp.). Of the rest, mostly young jack rabbits, only 3 were full grown in 1939 and 4 in 1940. These figures have some significance if contrasted with those of the Castleford 40-acre plot, where rabbitproof fencing was added to the livestock fence on October 1, 1944. Here no jack rabbit was seen inside or outside the plot during fencing and none was trapped within.

There seems to be no question that the numbers of jack rabbits were comparatively high prior to 1939 and that since 1941 they have been inordinately low and generally so for the part of the

Snake River plains represented by the plots. Whether the differences in destruction of vegetation and the effect on plant successions prior to 1939 needs to assume large differences in numbers of jack rabbits in the localities is a question.

During the period of greatest deterioration at Castleford plot and at field No. 21, the stand of weeds was so sparse that it would seem that the continuous feeding of comparatively few jack rabbits could destroy it. Damage here, though not excessive in terms of volume of vegetation destroyed, was nevertheless critical and resulted in bare, wind-swept soil. An equal volume of vegetation removed from a dense stand might scarcely be noticeable and have no pronounced effect on the changes in plant cover. The sparse stands were initiated by excessive grazing and trampling by livestock at Castleford and burning coupled with grazing at field No. 21.

In considering the total damage to vegetation by jack rabbits, there is the one kind that is localized, that is judged to be caused by continuous feeding on a comparatively small area, and ends in a bare area that increases in size over a number of years. To this is added the other kind of damage that causes a loss of forage and a reduction of carrying capacity on large areas and of the kind mentioned by Vorhies and Taylor (*14*), where the feeding of jack rabbits added to conservative grazing may produce a condition of overgrazing.

Mice

Of the other rodents that fed on the weedy plants, only the effect of the feeding of meadow mice was so marked that it could be separated from that of the others. With the meadow mice there were usually associated some whitefooted mice. Specimens of the meadow mice were identified by E. R. Hall and D. F. Hoffmeister, of the University of California, as *Microtus montanus nanus,* and those of the white-footed mice as *Peromyscus maniculatus sonoriensis.* The destruction of vegetation was attributed to meadow mice because of their much greater numbers.

Meadow mice were seen occasionally near old dead bushes of Russian-thistle, but the numbers were never large until at the downy chess stage of the vegetation, when they quickly and enormously increased. The numbers were greatest where there was a lush growth of downy chess with scattered dead bushes of Russian-thistle as protective cover. The conditions described refer to the areas not disturbed by either jack rabbits or livestock and where the current season's growth was mixed with the dried material of the preceding season. In areas normally grazed by livestock and where such excess material is removed each year the high numbers of meadow mice were not observed.

In the jack rabbit exclosure (1.8 acres) at Castleford, 101 meadow mice and 2 white-footed mice were killed above ground on March 30, 1940, as they ran out from the burrows when cyanide dust was blown into an opening. The number does not include those that remained in the numerous burrows. Trails were many and in some places not more than 6 inches apart. Above the shallow tunnels and around the runways narrow strips

of grass yellowed and dried. Downy chess was destroyed over about 10 percent of the area in 1941.

Meadow mice severely damaged the downy chess cover and caused a proportionately large percentage in loss of forage in the various exclosures, but they did not prevent the development of a downy chess cover. The greatest damage from meadow mice occurred subsequent to the development of a downy chess cover and resulted in the development of patches of mustards, more rarely of Russian-thistle, around each burrow or soil disturbance. To this extent there was retrogression and a reappearance of weed hosts.

Although the damage by meadow mice did not prevent the development of a downy chess cover there are indications that the perennial grass stage may be delayed by them in the areas closed to both jack rabbits and livestock. Individuals of Sandberg bluegrass, squirreltail, and sagebrush appeared early within the Castleford jack rabbit exclosure, but the tufts of perennial grasses were destroyed and even large-sized young sagebrush plants were stripped of their bark late in summer and killed. The same is now (1944) happening in the general weedy part of the Castleford plot where the downy chess cover is heavy. The results are not yet conclusive but indicate that retarded development of the perennial grass stage is due to the meadow mice harbored by the downy chess rather than competition or some other cause. At least at Burley where parent seed plants of squirreltail were more abundant and the small rodents fewer, the seedlings of this perennial grass established themselves in some parts of the downy chess cover and the area covered by squirreltail increased at the expense of the other.

Crested wheatgrass plantings near areas of dense downy chess were eaten by meadow mice at the crown late in summer and either killed or devitalized. Where the mice were not controlled the area of the stands of this grass decreased.

Damage to downy chess and, perhaps also, the destruction of perennial grasses by meadow mice may be less on lands conservatively grazed by livestock. Many of the abandoned fields have now been covered with downy chess for a long period without any apparent development of the perennial grass stage, presumably because of destruction of the first-appearing tufts. The relative effect on vegetation by livestock, jack rabbits, and mice is still in question.

Other Rodents

Information on other rodents in the areas studied is scanty. Local studies of rodents, which contrast kinds, numbers, and habits in weedy areas with those in the natural sagebrush-grass cover, are lacking and await the efforts of some future investigator trained in that field. No marked effect on the weedy vegetation was noted in connection with any of the following.

The sage chipmunk (*Tamias* sp.) had its burrows in the sagebrush cover, but, though it was seen feeding in the weedy areas, particularly on Russian-thistle late in summer, this rodent was judged not to play an important role in the destruction of vegetation on weedy areas. Davis (*4*) also reports the feeding of chip-

munks on seeds of Russian-thistle with no apparent reduction in the stands the following year. Heads of Sandberg bluegrass within the sagebrush half of the plots were cut down in considerable quantities at about the time of maturity of the seeds, either by chipmunks or by other small rodents resident in the sagebrush.

Ground squirrels (*Citellus* sp.) and kangaroo rats (*Dipodomys* sp.) were found where the cover was sparse. Their burrows were in drifted soil around old Russian-thistle or other plants. Neither seemed to be frequent within the plots.

Pocket gophers (*Thomomys* sp.) were found within the plots and occasionally nearby in the sagebrush cover, but only in a few places, and in the vicinity of perennial grasses and other perennials.

RELATION OF FINDINGS TO LAND USE AND RANGE PROBLEMS

Plant-Cover Value of Annuals and of Perennial Grasses

Some early investigations of the northern semidesert plains were concerned chiefly with the stable types of vegetation, composed of shrubs and perennial grasses (*7, 12*). Only in comparatively recent years and after much of the stable vegetation had been destroyed has the resultant weedy type of plant cover assumed large proportions and become of practical importance in both range and crop problems. In southern Idaho (*11*) surveys in 1934 showed 2,500,000 acres of weedy areas composed almost entirely of annuals and several more million acres of weedy sagebrush, in which the perennial grasses between the shrubs had been largely replaced by weeds.

The approach of the ecological studies in Idaho because of the curly top problem has been different from that of the investigations cited above and from the work of others in this region in this respect: The principal concern has been with a vegetation of annuals, one composed almost entirely of introduced plants and comprising only a very few species. These species form simple plant communities often surprisingly pure over large areas, and the communities form distinct stages of successions represented by a first stage of summer annual herbs, next one of winter annual herbs, and then one of winter annual grasses.

In the past, two stages usually have been recognized in a vegetation of annuals; one, an early weed stage, chiefly winter annual herbs, and a second, late, or annual, grass stage. These two stages are at present found on lands remote from cultivation and where the native annuals have not been killed and are still abundant. The first, or summer annual herb, stage is entirely lacking or represented by so few individuals as to be obscured by the prevailing winter annuals. In the fringe of lands bordering the cultivated tracts and pertinent to the curly top problem, such weedy areas are either not of large extent or they occur on lands still covered by sagebrush, and there they occupy the spaces between the sagebrush plants. Reference to weedy areas here

means those occupied by the introduced annuals and represented by the three stages. The constituents of the cover (figs. 5, 12, and 17) show the relative unimportance of other plants. The borages, representative of the native winter annuals, may become widespread some years but scattered, not dense, and never dominant over any sizable areas.

At times Russian-thistle, mustards, and downy chess, all of which are introductions, are referred to as "invaders," a term that conveys a loose or an incorrect meaning. These weeds are aggressive in that they cover bare soil quickly. They are poor competitors, particularly of perennials, and when they enter a perennial cover it is an indication that some of the perennials have been killed out and some soil space has been left unoccupied. When dealing with the curly top problem in crops, these weeds (especially Russian-thistle and mustards) have been spoken of disparagingly as a potential menace as hosts in producing large numbers of beet leafhoppers and other pests, but it should be kept in mind that all three "invaders" also have a beneficial effect in affording a cover for bare soil and in performing that function quickly. The question may be asked: What would the millions of acres of abandoned or denuded lands look like if these weeds were lacking? In some places native annuals might form a protective cover, though perhaps more slowly; in others, the lands might remain bare for a long period and in this time undergo considerable deterioration.

Under existing land use practices the weed hosts Russian-thistle and mustard are being replaced in some areas by downy chess, but this improvement is offset by the destruction of the downy chess cover on other areas, so that the hosts of the beet leafhopper again appear. If the annual grass stage is prevented from developing or if it is destroyed, the weed host acreage is increased, and large populations of the leafhopper that do not develop on the grass cover (*6*) are produced on the resulting stands of Russian-thistle and mustards. Thus, while there is no uncertainty as to which of these plant covers is desirable with regard to the curly top and leafhopper problem, the instability of the downy chess cover is a decided draw-back and forces the conclusion that it is only a temporary improvement. This question of the stability of a downy chess cover for a short period compared with a long one enters also into a consideration of its value as forage and as a protection against soil erosion.

In a particular year and for a given area it can be said that downy chess forms a cover that does not produce beet leafhoppers (*6*), that it may afford an early and desirable spring forage,[5] and that dense stands, if ungrazed and unburned, form a reasonably good protective cover for the soil (*5*). For the same area and over a period of several years, however, a downy chess cover fails in all these respects; in dry years its forage value may become next to nothing (*13*) ; it may also deteriorate in one season to a cover of leafhopper hosts, or in one or a few seasons it may

[5] STABLEIN, J. E. FORAGE AND FEED IN IDAHO DISTRICTS. U. S. Dept. Interior Grazing Bul. 2 (4) : 9–10. 1939. [Processed.]

be destroyed and the soil left wind-eroded and bare. In years of favorable rainfall, when there is a luxuriant growth of downy chess and a large supply of forage seems available, the fire hazard is great and large acreages are burned over.

From the long-time viewpoint the use of a plant cover of annual communities as forage would not be economical as compared with a cover of perennial grasses, because of the uncertainty of the forage and, under present conditions of grazing, because of the continuously lessened forage value due to deterioration of plant cover and soil. In contrast with this, the perennial grasses produce a good reliable supply of forage, which in drought years is many times greater than that from stands of annuals (*13*).

Indicator Value of Communities of Annuals

It would seem that as long as use of the land was such that the secondary plant successions leading to a reestablishment of the original vegetation would take place, there is no danger of deterioration of either plant cover or soil. If, however, the land is used in such way that there are merely fluctuations between the different kinds of weedy cover or if the stands are greatly thinned, there is danger that both the plant cover and the soil will deteriorate, since any one of the minor factors may bring about complete local annihilation of cover that is reduced to a sparse stand.

The reappearance of mustards and Russian-thistle year after year then is an indicator that the land is being badly misused and that an excessive quantity of vegetation is being removed by livestock and rodents; the reappearance of a good downy chess cover year after year is an indicator that the quantity of vegetation being removed is not excessive in the sense of causing deterioration and a return of weed hosts but still may be too much for development of the next stage of perennials leading to a reestablishment of the native perennials. That a downy chess cover may persist year after year under present use is now shown by fields under observation, as field No. 4 at Hollister (*9*), where it has persisted for 12 years (1932-44). In the area in figure 17, *C*, where the downy chess cover was known to exist in 1928, it has persisted for 16 years. There has been no noticeable development of the perennial grass stage, however, in these fields.

Prevention of Destruction of Vegetation to Obtain a Desirable Cover

Interpretation of the present findings and their possible application to the reestablishment of native perennials or to the establishment of some other desirable cover on the open range requires some limitation of the term "open range" as well as some definition and selection of the phases of the results thought to be significant. Moreover, since the present studies are not complete in themselves but are supplementary to previous studies, some general results on the abandoned fields near Hollister (*9*) also need to be considered.

The term "open range" if applied to southern Idaho as a whole

would include original types of vegetation ranging from mountain forest to salt desert shrub. With this go different kinds of weedy areas and the possible differences in kinds and numbers of rodents as well as a different use by livestock. The Snake River plains, a more uniform area, is nevertheless also different at its extremities with respect to the conditions just cited. On the other hand, the grazing lands bordering the cultivated tracts, though still a large area, are reasonably uniform, particularly with respect to the kinds of weedy areas.

For the reasons just stated, a direct application of the findings of these studies is limited. Some discussion along this line is given, but of more importance are the broader aspects that are judged to be applicable to other areas and other types of semi-desert vegetation.

One of the pronounced results within the fenced tracts is the effect of the feeding of jack rabbits. This can be stated briefly: Direct evidence in the restricted fenced areas shows that jack rabbits can cause excessive destruction of vegetation; that this has a drastic effect on vegetation and soil; and further that this effect can be continued for a number of years and over an increasingly large area. Similar effect on vegetation and soil occurred on unfenced tracts, such as field No. 21. Here there is no definite separation of the feeding of jack rabbits and of grazing by livestock, but observations on the ground seemed convincing that the effect was due to jack rabbits, as at the Castleford plot. A condition present in both fields was a sparse stand of weeds. This was initiated in the one by livestock and in the other by the combined effect of fire and livestock.

Although the pronounced effect, as in field No. 21, was localized, the total of such areas on the grazing lands under consideration was thought to be worthy of attention. Moreover, the potential area for such an effect seems great and an increase toward that potential is dependent directly or indirectly on man's activities. It is safe to assume recurrence of dry periods of years and presumably of moderate to high numbers of jack rabbits. With these conditions present it is only necessary to assume an increase in the areas of sparse weedy stands such as those at Castleford plot and field No. 21. This is precluded only if it is assumed that there will be conservative grazing by stock and also that such grazing will not damage the cover on burned areas sufficiently to bring about the sparse weedy stands. Considering the possibilities outlined it would seem to be a form of insurance to be aware of the deterioration that may occur on these grazing lands and, if necessary, to reduce the number of jack rabbits wherever an attempt is made at rehabilitation.

Aside from this localized effect in certain weedy areas there is the more widespread destruction in the sagebrush-grass cover of the grazing lands and in the weedy areas where the stands are dense. Here the damage caused by jack rabbits is more closely interwoven with that of livestock. This more widespread effect of jack rabbits in the sagebrush-grass vegetation also prevents or delays obtaining a desirable cover in the sense of reestablishment of native perennials. This is based in part on the evidence in the Burley plot and also on more general observations that support

the statement by Vorhies and Taylor (*14*) that the feeding of jack rabbits when added to conservative grazing by livestock may at times produce a condition of overgrazing. In a period of dry years it may not be enough to maintain grazing by livestock at a conservative level: the number of jack rabbits may need to be reduced if the development of the cover of native perennial grasses is to be obtained in a given time and over a given area.

These instances of a more direct but also a more limited application of the results of the studies seem less important than the more general interpretation that may apply to other areas of vegetation and to other rodents. In attempting to obtain a desirable cover by proper plowing, burning, and control of grazing, if there is lack of success either in a given time or in completeness as to space, then some other cause should be sought—rodents or insects—before attributing the failure to drought, competition, or soil condition. In other words, prevention of a partial failure to obtain the desired cover under the conditions stated would mean searching at the outset for evidence of excessive feeding of rodents; if found, a reduction in their numbers would insure a higher degree of success.

There is another indication in these results on which the preceding interpretations touch and which at first glance seems only of limited technical interest but obviously affects economic aspects. This has to do with the methods of investigation. Various ecological techniques have been devised and are used to determine the extent (the space) covered by a given kind of vegetation, but the writer knows of no equally satisfactory technique that is being used to determine the time in which a given area is to be covered. There is no established optimum rate against which success can be measured.

The difficulty lies in establishing the time. The stages of succession are usually outlined, but there is not often a commitment as to time, or if so, an estimate is given. The reason for this rests largely on the method of investigation. Clements, in his discussion (*3, p. 186*), lists three primary methods of investigating plant succession: "(1) By inference; (2) by sequence; (3) by experiment." The method of inference (piecing together information obtained on many parcels of land) gives much information as to the stages of development, but the question of time (the rate) remains vague because of the complex conditions under which observations are made. Destruction of vegetation, for instance, which causes deterioration and retards or prevents development, may vary greatly from one parcel of land to another. Sequence (the following of actual development on the same area for a period of years) affords more information in this respect but requires further verification. Year-after-year records of development to a downy chess stage on a number of fields near Hollister (*9*) fall under the method of sequence. First attempts to verify these findings by setting up the three 40-acre plots failed, but there was success when feeding by jack rabbits as well as grazing by livestock was prevented. Eventually the length of time for a downy chess cover to develop under a minimum of destruction of vegetation was determined by repetition, by experi-

ment. If certain conditions were fulfilled it became possible to predict the results.

Here it seems are the essentials of the results: Demonstrating the use of the method of experiment in dealing with plant successions in a vegetation of annuals and also possibly extending this to include the stages of perennials as indicated by the Burley plot, thereby reproducing by this means the stages of development and determining the optimum (or near optimum) rate of development for any given type of semidesert vegetation or for its subdivisions. The optimum rate becomes a measure or standard against which the rate on a rehabilitation project can be measured. The knowledge acquired in determining the rate can then be applied to the rehabilitation of some given area—by fulfilling the necessary conditions insofar as economically feasible and by shortening to that extent the length of time required to obtain the desirable cover. If use of a parcel of land is curtailed or prohibited while the desired cover is being established, a monetary value can be put on any increase or decrease in the total time during which the land is retired.

Applying the method to the area of which the plots are representative, the results to date set the time for a development of a downy chess cover as 5 years. In the Castleford plot the time was 13 to 14 years where grazing by livestock alone was prevented, but it was only 5 years when jack rabbits also were excluded. The question may not be one of complete success as against complete failure but rather a higher degree of success either by shortening the time for the desired changes to take place or by increasing the space covered by the desired vegetation in the given time. Assuming that 7 out of 10 abandoned fields show development of a downy chess cover in 5 years, with no control of jack rabbits and with light grazing by livestock, and further assuming that by reducing the number of jack rabbits the number of successful fields is increased from 7 to 9 or 10, it may be a gain worthy of economic consideration. If all 10 of the fields showed a development to downy chess but with development slowed down to an estimated 10 to 12 years instead of the desired 5 years, here again the difference seems worthy of consideration.

In a period of dry years coupled with moderate to high numbers of jack rabbits, at least some of these fields (as field No. 21) may be bare for a number of years instead of producing forage, so that in a long-time view it is not merely the total acreage of the localized effect in any given season that is involved, but actually such acreage multiplied by the number of years in which it is bare and nonproductive. Assuming light grazing by livestock, the amount of vegetation destroyed by rodents at a given locality may be a less important consideration than the destruction of the plant cover at a critical phase in its development.

The illustrations just given have to do with a vegetation of annuals and a development within 5 years. Reestablishment of native perennials seems more difficult and requires a longer time. Judging from the results on the Burley plot, however, there is indication that present concepts of the slow rate of recovery on such lands will need to be changed. More information is necessary and particularly of the kind with conditions such as at the

Castleford plot, where initial tufts of perennial grasses are few and where the downy chess cover is well established.

Some phases of the use of a standard or check where destruction of vegetation by any cause is reduced to a minimum and where the optimum rate of change in vegetation may be determined has been discussed elsewhere (*10*). This seems applicable to other areas and to other types of vegetation and may help to supply answers to questions such as the following: In a semidesert area, where the number of plants to the unit soil space is naturally low, if excessive grazing by domestic and native animals once reduces the vegetation to a very low level, is it possible that the desert fauna may thereafter maintain the vegetation at that low level even if grazing by livestock is eliminated? In other words, is it necessary in some areas to reduce the populations of rabbits and other rodents as well as the grazing by livestock if improvement is to be expected in a given time?

In some semidesert areas where annuals now occupy the spaces between desert shrubs it is not known whether perennial grasses were originally present or could maintain themselves. By use of a standard plot, where destruction of vegetation is held to a minimum, it could be determined whether under the given conditions of soil and climate the perennial grasses could grow and spread.

In the standard plot the results are predictable, but not on the open range, where the effect of drought, soil, competition, and varied feeding by animals may all be involved. There may be improvement, deterioration, or fluctuations from one condition to another. If a species is eliminated from the plant cover, is this due to competition, to drought, or to the fact that it was killed out by feeding by animals? If a species increases in abundance, is it due to its aggressiveness, to a series of wet seasons, or to the killing out of an important competitor? Demonstrations as to which of these operates at a given time or locality will determine or modify the approach to the economic phases of the problem.

Lack of success with some plantings of perennial grasses might easily have been ascribed to drought had there not been available other plantings of the same date where (under adequate protection against destruction) the perennial grasses grew well. Likewise, some of the changes in plant cover that are presented in this circular would not have been understandable without the use, as checks, of areas protected against destruction of vegetation by any cause.

There are objections to the method. The one most commonly met is that the unremoved plant growth of each season soon hampers further development. An answer to this will serve for most of the other objections that come to mind: Insofar as the unremoved growth does this, it is worth continuing and recording. The obvious remedy seems to be to set up an additional area where destruction of vegetation is held at a minimum and where the excess dried material is removed at some time during the dormant season. Any number of areas may be added for the purpose of obtaining information along still other lines. But it seems plain that a part should be reserved where destruction of vegetation is held at a minimum and where the reactions of the plant communi-

ties under such conditions can be observed and recorded. The real obstacles are two: The length of time required when dealing with long-lived plants and, in any case, the effort required to hold destruction from any cause at a minimum.

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